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Review of the stalked barnacle genus *Koleolepas* (Cirripedia: Thoracica: Koleolepadidae), with new records from Australian waters

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ABSTRACT – The stalked barnacle family Koleolepadidae is found exclusively in association with hermit crabs (*Dardanus* spp.) carrying sea anemones (*Calliactis* spp.). New records of *Koleolepas avis* and *K. willeyi* are herein reported, respectively, from near Ningaloo, Western Australia, and Christmas Island, an Australian territory in the Indian Ocean. Previously these species were known only from the East China Sea and southern Japan (*K. avis*), and the Loyalty Islands (*K. willeyi*). Both species are redescribed and figured. Type material of *K. tinkeri* and *K. willeyi* were examined and *K. tinkeri* is considered a junior subjective synonym of *K. willeyi*.

KEYWORDS: Crustacea, Diogenidae, Hormathiidae, epibiotic, symbiosis, parasitism, Ningaloo Marine Park, Christmas Island, Western Australia

INTRODUCTION

Members of the little known stalked barnacle family Koleolepadidae Hiro, 1933 are notable for being the third wheel in the well known symbiotic relationship between hermit crabs and sea anemones. These barnacles attach to the gastropod shell inhabited by the hermit crab, typically underneath the sea anemone's pedal disc. This peculiar habit is enabled by the unique, expanded, adherent pad that forms a sheath into which the peduncle and capitulum can retract. Thus, by fully retracting and extending the capitulum from under the sea anemone, they mitigate predation and are able to feed. Their unusual habitat has led to an unusual parasitic diet of feeding on the tentacles of the host sea anemone (Yusa and Yamato 1999). To date, the Koleolepadidae have only been found associated with sea anemones of the genus *Calliactis* Verrill, 1869, attached to gastropod shells inhabited by hermit crabs of the genus *Dardanus* Paulson, 1875.

This monogeneric family contained three nominal species, *Koleolepas avis* (Hiro, 1931), *K. tinkeri* Edmondson, 1951 and *K. willeyi* Stebbing, 1900. Only *Koleolepas avis* has been recorded since its original description (e.g. Liu and Ren 1985, 2007; Yusa and Yamato 1999; Yusa et al. 2001). Recent material from Australian waters in the Indian Ocean has prompted a reassessment of these species.

METHODS

Specimens were examined from the Natural History Museum (NHM), London, the Bernice Pauahi Bishop Museum (BPBM), Honolulu and the Western Australian Museum (WAM), Perth. Specimens were examined and dissected under a Leica MZ16 microscope. The total length (TL) was measured from the base of the adherent pad to the apex of the capitulum. Cirri and mouthparts were stained with lignin pink, mounted on slides and examined under an Olympus BX50 microscope. Line drawings were prepared using a camera lucida and digitally inked using a Wacom Intuos II drawing tablet and Adobe Illustrator. Photographs were taken using a Leica DC500 and DFC420. The map (Figure 1) was produced using the ArcGIS online mapping tool (www.arcgis.com).

SYSTEMATICS

Order Lepadiformes Buckeridge and Newman, 2006

Suborder Heteralepadomorpha Newman, 1987

Family Koleolepadidae Hiro, 1933

Genus *Koleolepas* Stebbing, 1900

TYPE SPECIES

Koleolepas willeyi Stebbing, 1900, by monotypy.

DIAGNOSIS

Hermaphrodites; capitular plates absent except for slender chitinous scuta, often further reduced or absent on one or both sides; crest running from orifice along distal-posterior margin. Peduncle naked, retractable into expanded oval, sheath-like, adherent pad. Mandible quadripartite, two medial processes serrate. Cirrus I pedicel with filamentary appendage; rami subequal, posterior rami of cirri II–VI much narrower than anterior rami; anterior rami of cirri II–VI with distal segments bearing stout, acute setae at postero-distal angles. Caudal appendages much shorter than pedicel, uni-articulate.

Complemental male globular, crest and sheath absent; scuta present. Mouthparts and cirri similar to hermaphrodite; penis well developed.

REMARKS

The complemental males retain seemingly functional cirri and mouthparts. Owing to their small size it is doubtful that they are still able to independently feed on tentacles. Surprisingly, the complemental males were not recognised as such when the species of *Koleolepas* were described, but were referred to as a 'projecting bulb' (Stebbing 1900; Hiro 1933) or 'bulbous process' (Edmondson 1951) and suggested to provide support for the capitulum (Stebbing 1900). This, even though Hiro (1933) reported a metamorphosing cypris larva attached near the orifice of a small individual of *K. avis*.

The members of *Koleolepas* have been recorded from Japan, East China Sea, Hawaii and the Loyalty Islands and are reported herein from Australia and Australian territorial waters in the Indian Ocean (Figure 1).

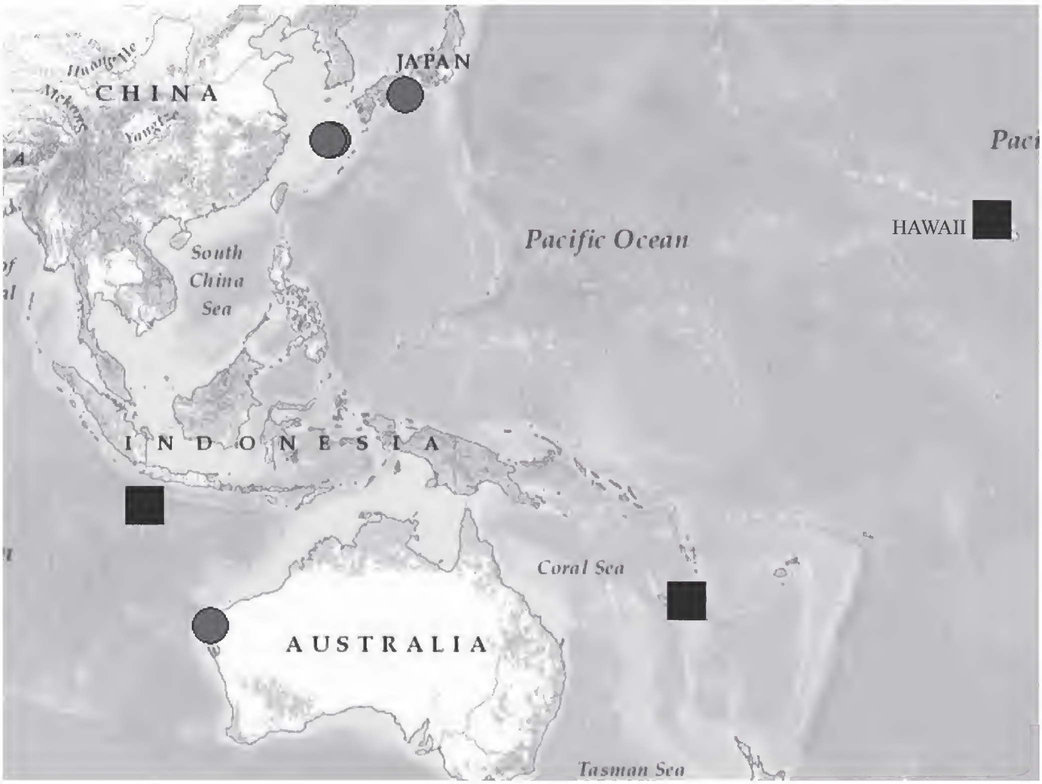

FIGURE 1 Map of known records of *Koleolepas avis* (Hiro, 1931) ( ) and *K. willeyi* Stebbings, 1900 (■).

Koleolepas avis (Hiro, 1931)

Figures 2, 3

Heteralepas avis Hiro 1931: 147, figures 4, 5, plate 11, figure 3.

Koleolepas avis (Hiro): Hiro 1933: 239, figure 4, plate 9 figures 4–6; Utinomi 1958: 307; Utinomi 1971: 510, figure 621; Zevina 1982: 145, figure 132; Liu and Ren 1985: 271, figure 53, plate 7; Liu and Ren 2007: 130, fig. 44.

MATERIAL EXAMINED

Australia: ***Western Australia*:** WAM C45480, 3 hermaphrodites, TL 15.6–25.9 mm, ~72 km SW of Coral Bay, 23°26 30 S 113°08 00 E, 220–230 m depth, G. McKewan, 18 February 2010.

DIAGNOSIS

Koleolepas hermaphrodites with orifice lips characteristically projecting beyond capitular crest, internally bearing 3 teeth near apical margin; scuta crescent shaped, present on at least one side; labrum with cutting edge bluntly V-shaped; cirrus I with long, posteriorly directed filamentary appendage at base of pedicel.

DESCRIPTION

Hermaphrodites

Capitulum smooth, not clearly demarcated from peduncle, distinctive capitular crest extending from orifice along postero-distal margin. Scutum chitinous, crescent shaped, curving away from orifice apically, reduced or absent on lower capitular side. Orifice lips triangular, projecting beyond crest, internally 3 teeth on apical margin. Peduncle smooth, 3 times longer than capitulum. Adherent disc ovoid, approximately two thirds total length.

Labrum with crest deeply concave, bluntly V-shaped, with row of 47 acute teeth, 23 straight medial teeth, lateral teeth curved medially. Palps short, subtriangular not extending medially beyond lateral edge of labral crest, single row of simple setae on margins. Mandible quadripartite, superior angle molariform followed by pectinate notch with 8 teeth, medial processes approximately equal in size, serrate with 7 and 8 teeth on upper and lower processes, respectively, separated by small pectinate notch with 4 acute teeth; inferior angle projecting, with 3 acute teeth. Maxilla I with cutting margin almost straight, 3 teeth of descending size located at superior angle, midpoint and half way between midpoint and inferior angle of margin; 2 stout setae immediately below superior tooth, separated from following stout setae by slight notch, remaining 13 stout setae more or less evenly distributed along cutting margin. Maxilla II subrectangular, sparsely setose along margins.

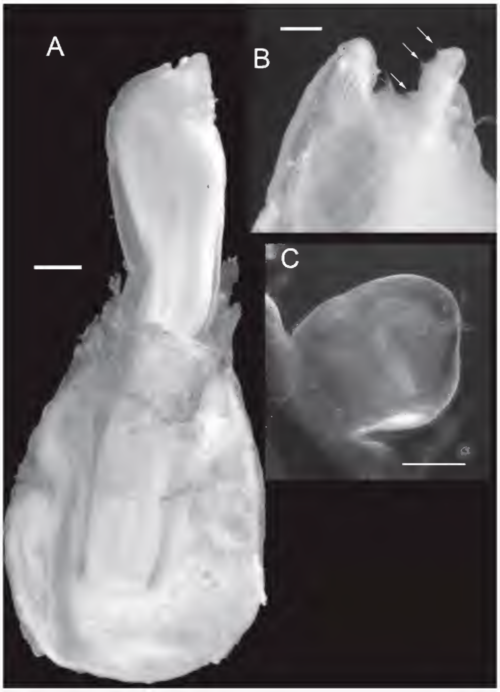

FIGURE 2 *Koleolepas avis* from west of Coral Bay, Western Australia (WAM C45480, TL = 25.9 mm). A, lateral view of hermaphrodite; B, close up of orifice, arrows indicate the orifice teeth; C, complemental male. Scale bars: A = 2 mm; B and C = 0.5 mm.

Cirrus I well separated from posterior pairs; posteriorly directed filamentary appendage near base of basal segment of pedicel, approximately as long as pedicel, tapering distally; rami subequal, approximately equal in length to pedicel, densely setose with simple and finely plumose setae. Cirri II–VI similar, pedicels becoming progressively smaller posteriorly; cirrus II with width of basal segment of pedicel 2 times width of distal segment; cirrus VI with width of pedicel basal segment 1.3 times width of distal segment; cirri II–VI with rami equal or shorter than pedicel length; anterior rami segments 1.5 times wider than respective posterior rami segments, chaetotaxy acanthopod, anterior margins sparsely setose, postero-distal margins of 4 distal-most segments armed with stout, acute, claw-like setae, antero-distal margins with 1–2 long, simple setae; posterior segments of rami becoming

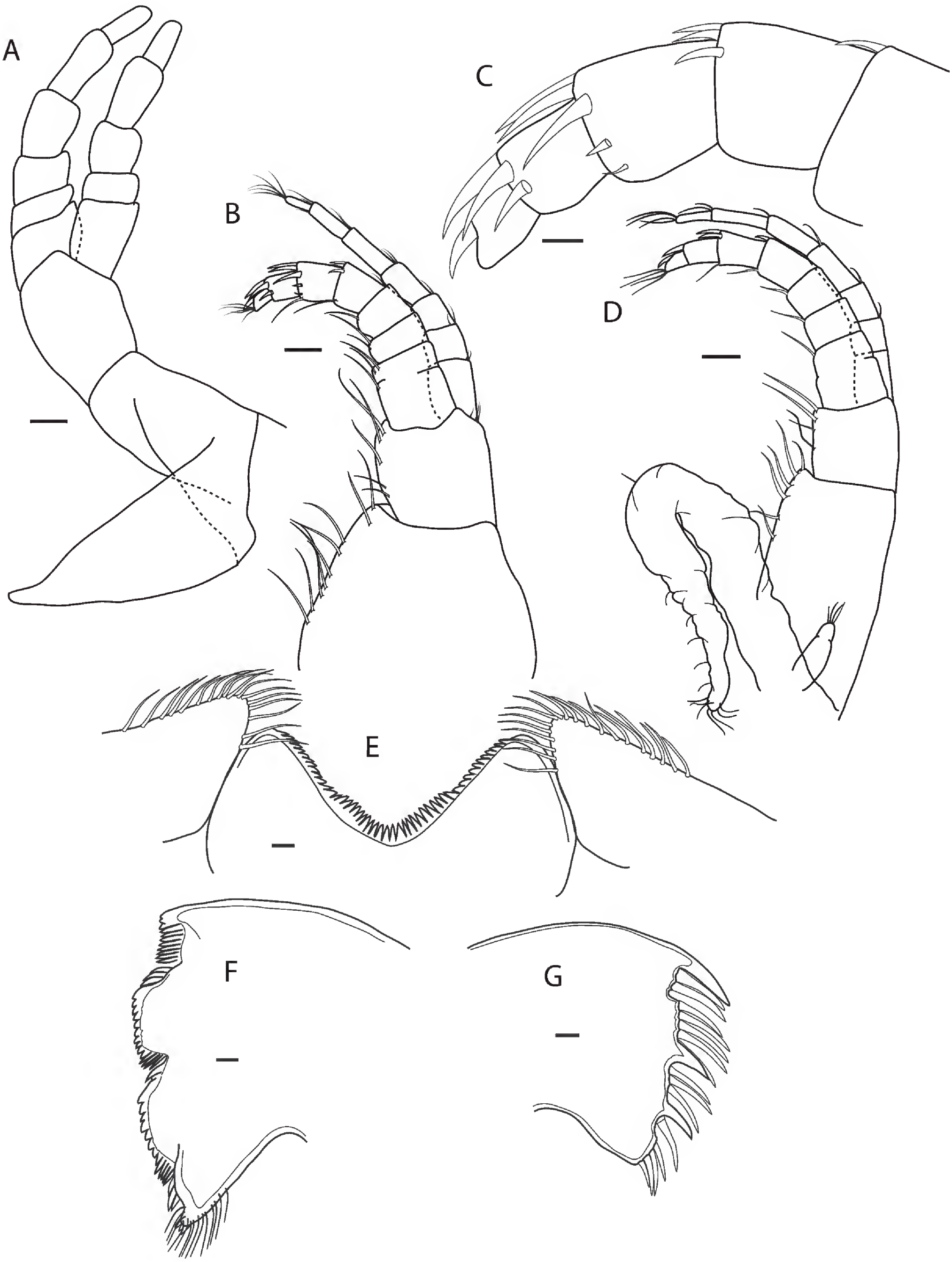

FIGURE 3 Cirri and mouthparts of *Koleolepas avis* hermaphrodite (WAM C45480, TL = 25.9 mm). A, right cirrus I; B, right cirrus II; C, terminal segments of anterior ramus of right cirrus II; D, right cirrus VI with penis and caudal appendage; E, labrum and mandibular palps; F, right mandible; G, left maxilla I;. Setation completely omitted from A; only claw-like setae shown in C; fine setae omitted from F and G. Scale bars: A, B and D = 150 µm; C, E–G = 50 µm.

elongate distally, chaetotaxy sparse, 1–2 simple setae present at postero-distal and antero-distal margins, terminal segment with tuft of 4–6 setae distally. Cirral segment counts as follows (* denotes damaged cirri):

	CI	CII	CIII	CIV	CV	CVI
L	5,5	8,7	8,8	8,8	8,8	8,7
R	6,5	8,7	8,7	8,5*	8,7	8,7

Caudal appendage uni-articulate, less than half length of basal segment of pedicel of cirrus VI, small tuft of setae apically. Penis approximately as long as cirrus VI, obscurely annulated, sparsely setose.

Complemental males

Globular, attached to hermaphrodite scuta near orifice. Capitular crest absent; peduncle very short, sheath absent; scuta bent, tapering apically. Cirri and mouthparts similar to hermaphrodites; penis longer than cirri.

HOSTS

Calliactis japonica Carlgren, 1928 (Yusa and Yamato 1999; present specimens WAM Z27714) attached to *Bufonaria bufo* (Bruguière, 1792) shell inhabited by *Dardanus arrosor* (Herbst, 1796) (WAM C45477). Other hosts include *D. crassimanus* (H. Milne-Edwards, 1836) (see Yusa et al. 2001 for details on inhabited gastropod shells). Hiro (1931) did not mention any sea anemones in his description of *K. avis*, but later, erroneously identified the host as *Calliactis parasitica* (Couch, 1842) (as *Adamsia rondeleti* Delle Chiaje, 1841), an Atlantic species (Hiro 1933).

DISTRIBUTION

Sagami Bay, Japan (type locality), East China Sea (Liu and Ren 1985), northern Western Australia. 10–230 m.

REMARKS

This is the most studied species of *Koleolepas*, having also been the subject of behavioural and ecological studies (Yusa and Yamato 1999; Yusa et al. 2001). These studies showed that the barnacles feed by cropping the tentacles from the sea anemones and that the asymmetry of the scuta develops with ontogeny, with the reduced scutum occurring on the lower side of the capitulum of older individuals. The barnacles tend to lie on their side along the lower edge of the anemone, with their orifices typically oriented towards the shell's aperture (Yusa et al. 2001).

The material agrees well with previous figures and descriptions. However, Hiro (1933) states that the first pair of cirri are shorter than the remaining pairs, but in the current specimens the rami are subequal in length. The figures of *K. avis* presented by Liu and Ren (1985, 2007) show the terminal segment of the anterior rami of cirri II and III as lacking the single claw-like seta. A slight constriction about one third from the apex of the right caudal appendage (Figure 3D) gives the impression that it may be bi-articulate, rather than uni-articulate as is the left caudal appendage and as described by Hiro (1931, 1933).

Koleolepas willeyi **Stebbing, 1900**

Figures 4, 5

Koleolepas willeyi Stebbing 1900: Stebbing, 1900: 677, plates LXXIII, LXXIVD; Zevina 1982: 146, figure 133.

Koleolepas tinkeri Edmondson 1951: 185, figure 1; Zevina 1982: 146, figure 133.

MATERIAL EXAMINED

Loyalty Islands: NHM 1906.4.19.148, 1906.4.19.164 and 1906.4.19.165, Holotype, hermaphrodite, TL ~26 mm, Lifu Islands, depth unknown, A. Willey, 10 February 1897. **Hawaii:** BPBM B351, holotype of *K. tinkeri*, TL 28.5 mm, Oahu, off Ewa, 29 m, S.W. Tinker, 31 May 1948; BPBM B354, 3 dry hermaphrodites, TL 15–16 mm, Oahu, off Ewa, depth unknown, S.W. Tinker, 19 October 1948; BPBM B767, 1 hermaphrodite, TL 17.5 mm, Hawaii, depth unknown. **Christmas Island (Indian Ocean)**: WAM C49720, 3 hermaphrodites, TL 11.7–28.6 mm, Flying Fish Cove, 10°25 42 S 105°40 7 E, depth unknown, G.J. Morgan, 22 February 1987.

DIAGNOSIS

Koleolepas hermaphrodites with orifice lips not projecting beyond capitular crest, bearing 2 internal teeth near apical margin; scuta present on at least one side; labrum with cutting edge broadly U-shaped; cirrus I with long, posteriorly directed filamentary appendage at base of pedicel.

DESCRIPTION

Hermaphrodites

Capitulum smooth, not clearly demarcated from peduncle, capitular crest extending from orifice along postero-distal margin. Scutum chitinous, apically bent away from orifice, reduced or absent on lower capitular edge. Orifice lips not projecting beyond crest, internally 2 teeth apically. Peduncle smooth, cylindrical, 3 times longer than capitulum. Adherent pad subcircular to ovate, up to 0.5 times total length.

Labrum crest deeply concave, broadly U-shaped with row of 44 acute teeth, 32 straight medial teeth, lateral teeth curved medially. Palps subtriangular, short, not extending medially beyond lateral edge of labral crest, single row of simple setae evenly spaced on margins. Mandible quadripartite, superior angle molariform followed by pectinate notch with 5 acute teeth, medial processes serrate with 6 and 8 teeth on upper and lower

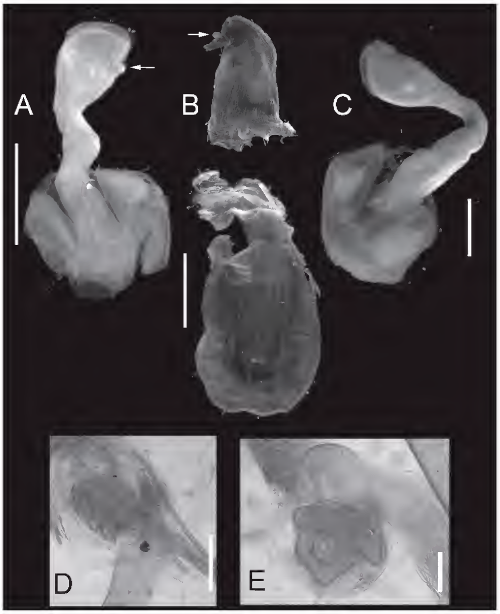

FIGURE 4 *Koleolepas willeyi* Stebbing, 1900. A, lateral view of hermaphrodite from Christmas Island (WAM C49720 TL = 11.7 mm); B, detached capitulum and peduncle of holotype of *K. willeyi* (NHM 1906.4.19.148); C, holotype of *K. tinkeri* Edmondson, 1951 (BPBM B351); D and E, coiled structure presumed to be the oviducal gland at the base of the right and left cirrus I, respectively. Arrow indicates position of complemental males. Scale bars: A = 5 mm; B and C = 200 μm.

processes, respectively, bordered by small pectinate notches with acute teeth; inferior angle projecting with 1 acute tooth and long simple setae. Maxilla I with cutting margin almost straight, 3 teeth of descending size located at superior angle, midpoint, and half way between midpoint and inferior angle of cutting margin; 2 stout setae immediately below superior tooth, separated from following setae by slight notch; remaining 14 stout setae more or less evenly spaced along cutting margin. Maxilla II subrectangular, sparsely setose on margins.

Cirrus I well separated from posterior pairs; posteriorly directed filamentary appendage near base of basal segment of pedicel, approximately as long as pedicel, tapering distally; pedicel approximately as long as rami; coiled oviducal gland prominent, located basally on basal segment of pedicel; rami equal, densely setose with plumose setae. Cirri II–VI similar, pedicels becoming progressively smaller posteriorly. Cirrus II and VI with width of pedicel of basal segment 2.4 and 1.4 times width of distal segment, respectively. Chaetotaxy of cirri II–VI anterior rami acanthopod, segments broad, up to 2 times corresponding width of segment of posterior ramus, anterior margins sometimes with 1–2 simple setae, postero-distal margins of 4 terminal segments armed with claw-like, stout acute setae; posterior ramal segments becoming elongate distally, chaetotaxy sparse, antero-distal and postero-distal margins sometimes with 1–2 simple setae. Cirral segment counts as follows (* denotes damaged cirri):

		CI	CII	CIII	CIV	CV	CVI
WAM C49720	L	5,5	7,6	7,8	7,6	7,6	7,6
(TL 18.2 mm)	R	5,5	7,6	8,7	8,6	7,6	7,6
BPBM B767	L	5,3*	7,6	8,7	8,7	7,7	7,7
(TL 17.5 mm)	R	5,5	7,7	8,7	8,7	7,7	7,7

Caudal appendages uni-articulate, approximately half length of basal segment of pedicel, tuft of simple setae apically. Penis thick, length subequal to cirrus VI, obscurely annulated.

Complemental males

Globular, attached to hermaphrodite scuta near orifice. Capitular crest absent; peduncle very short, sheath absent; scuta bent, width similar throughout length. Cirri and mouthparts similar to hermaphrodites; penis longer than cirri.

HOSTS

The type hosts were only recorded as being 'Pagurid' and 'Actinian' by Stebbing (1900). In Hawaii, this species is associated with *Calliactis polypus* (identified as *C. armillatas* Verrill, 1928 in Edmondson 1951) but the host hermit crab is unknown. The Australian material is associated with *Calliactis polypus* (Forsskål, 1775) (WAM Z27715) attached to the shell of *Turbo lajonkairii* Deshayes, 1839 inhabited by *Dardanus gemmatus* (H. Milne-Edwards, 1848) (WAM C42013).

DISTRIBUTION

Lifu, Loyalty Islands (type locality); southwest Oahu, Hawaii (Edmondson 1951); Christmas Island, Indian Ocean; to 30 m depth.

REMARKS

The holotype is represented by the empty capitulum, peduncle and sheath in ethanol as well as two slides with the mouthparts and cirri on one, and an egg mass and section of peduncle integument on the other. The slide bearing the mouthparts and cirri has deteriorated, with the mountant retracting around many of the limbs, however many details are still recognisable allowing a reasonable comparison with the Hawaiian and Australian material.

Stebbing's (1900) original description specifically stated that the capitulum had no valves, however, the holotype clearly has paired, chitinous scuta. He also omitted the presence of the large filamentary appendage

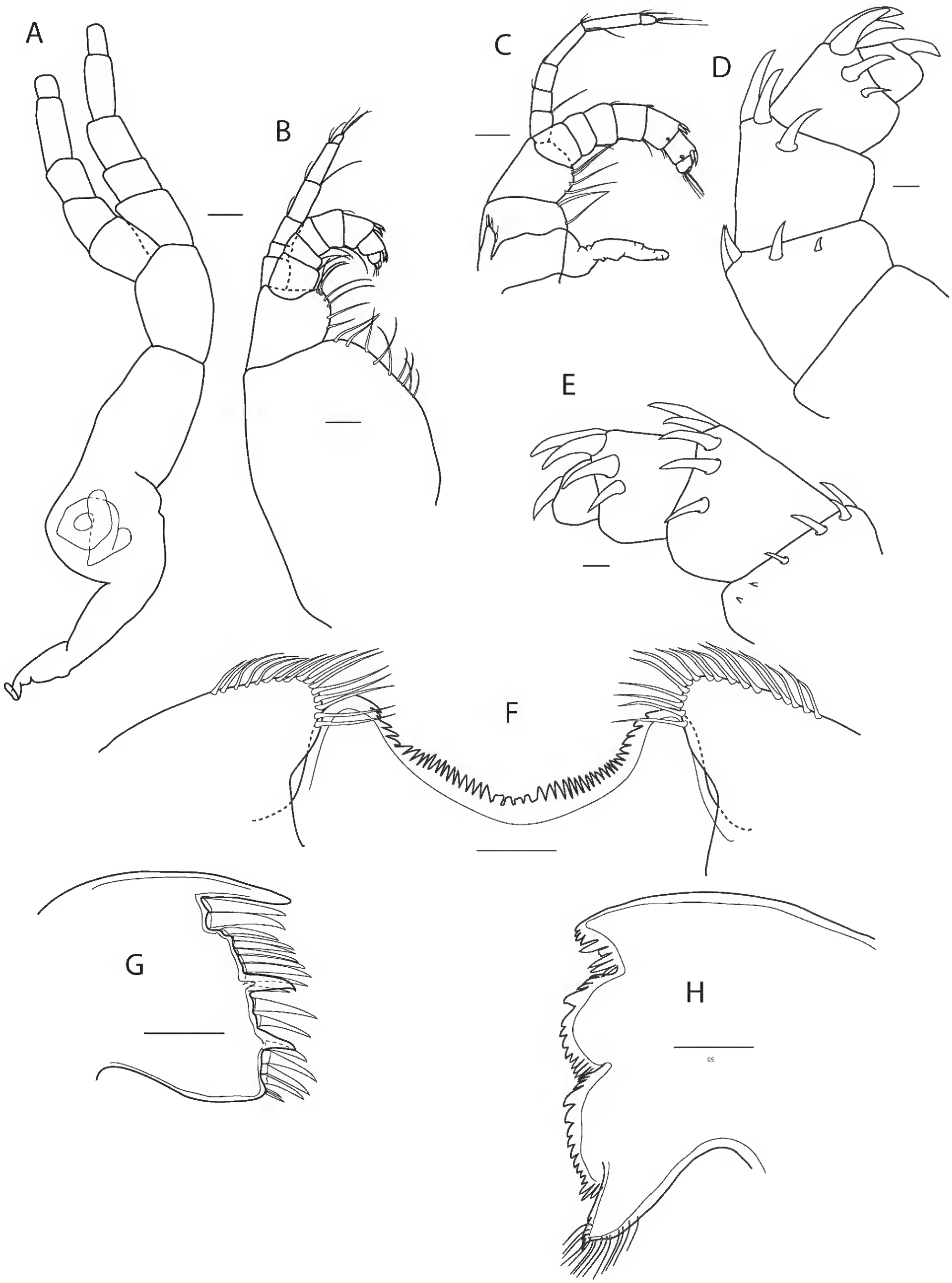

FIGURE 5 Cirri and mouthparts of *Koleolepas willeyi* hermaphrodite (WAM C49720, TL = 18.2 mm). A, right cirrus I; B, left cirrus II; C, left cirrus VI with penis and caudal appendage; D and E, terminal segments of anterior rami of cirri II (left) and III (right), respectively; F, labrum and mandibular palps; G, left maxilla I; H, right mandible. Setation completely omitted from A; only claw-like setae shown in D and E; fine setae omitted from G and H. Scale bars: A–C and F–H = 150 μm; D and E = 50 μm.

on the pedicel of cirrus I which is visible on only one of the first cirri, albeit mostly obscured by the retracting mountant. There is also no mention of a penis in his account, and there appears to be no trace of this organ on the slide. However, one of the cirri, possibly the sixth, is also missing from the slide, and perhaps had the penis attached to it. The Hawaiian specimens examined also appeared to lack a penis, but no other differences in the specimens were seen. The penis is absent in the smallest specimen from Christmas Island, but this individual does have a complemental male. Gonochoristic specimens, identified as *Koleolepas* sp., were reported by Yusa et al. (2011), but no further detail was given. As all of the dissected Hawaiian specimens are smaller than the specimen in Figure 4, it is suggested that penis development occurs at maturation, or is linked to the reproductive cycle as has been reported in other barnacles (e.g. Klepal 1990; Brickner et al. 2010).

The holotype of *K. tinkeri* was not dissected by Edmondson and nor was it in this study. The specimen, or specimens, that were dissected could not be located within the BPBM. Edmondson separated his species from *K. willeyi* on the grounds that Stebbing makes no mention of the filamentary and caudal appendages. However, the filamentary appendage was simply omitted as described above and Stebbing described the 'pleon', as being minute, and they are uni-articulate in his figure (Stebbing 1900, LXXIIIT), which is herein interpreted as referring to the caudal appendages. Further distinguishing characters listed by Edmondson included *K. tinkeri* having smaller palps that do not extend medially past the lateral borders of the labrum, and the lower serrate process of the mandible being truncate (as opposed to convex in *K. willeyi*). However, differences between the shape of the mandible and the relative size of the palps could be a result of differences in how they were examined or mounted on slides. The specimens examined in this study showed no appreciable differences between the palps, labrum or mandibles of the holotype of *K. willeyi*. Therefore, *K. tinkeri* is considered to be a junior subjective synonym of *K. willeyi*.

Characters distinguishing *K. avis* from the present species are subtle, with the exception of the projecting orifice, which gives the former species a distinctive appearance. In the present material, *K. willeyi* has relatively stouter cirri and, correspondingly, the claw-like setae are also more robust. The margin of the labrum in *K. willeyi* is more evenly curved compared with *K. avis*, which is more v-shaped. The serrations on the mandibles are also coarser and there are less pectinate spines in the notch between the superior angle and the upper serrate process of *K. willeyi*.

At the base of the pedicel of cirrus I is a coiled structure that is presumed to be the oviducal gland through which oviposition occurs (see Figures 4D, E and 5A). This prominent structure is not mentioned in the original description of *K. tinkeri* or for *K. avis*, but is clearly evident in the figure of *K. willeyi* by Stebbing although not described in the text (1900, pl. LXXIII, Cir. 1). The dissected specimen of *K. avis* was ovigerous but lacked this coiled gland. This, coupled with the prominence of the oviducal glands in the present species suggests that the *K. tinkeri* individual was entering a reproductive phase when collected (Walker 1980).

DISCUSSION

The present specimens of *Koleolepas avis* and *K. willeyi* represent significant range extensions from the East China Sea and Loyalty Islands, respectively, by several thousand kilometres into Australian territorial waters of the Indian Ocean. Based on known ranges of the hosts, however, both of these species can be expected to be found throughout the tropical Indo Pacific region.

To date, only two host species have been identified, *Calliactis japonica* and *C. polypus*. Yusa et al. (2001) found that *K. avis* was present on ~44% of shells with *C. japonica*, but none with *C. polypus* in Tanabe Bay, Japan, suggesting that at least *Koleolepas avis* is restricted to a single host species. The current material supports this hypothesis, but further studies would be required to confirm this.

The genus *Pagurolepas* Stubbings 1940 is also found in association with hermit crabs, but are instead attached to the interior of the gastropod shell and are not known to be associated with sea anemones. The trophi in this genus are of a more normal shape with the exception of the much reduced cutting margin of maxilla I (see Keeley and Newman 1974). The cirri are reduced even further than *Koleolepas* but are densely setose with long fine setae, similar to cirrus I of *Koleolepas* spp. The terminal segments of each cirri also bear smaller acute, stout spines. These features show clear adaptations to different modes of feeding between *Pagurolepas* and *Koleolepas* although the diet of *Pagurolepas* is unknown. The capitular plates on the side of the *Pagurolepas* that lies against the gastropod shell become reduced with size, in much the same way as species of *Koleolepas*.

While the koleolepadids have a unique morphology for a unique life history, similarities can be seen in the saw-like mandibles of species of the pyrgomatid tribe Hoekini Ross and Newman, 1995, which is parasitic on its coral hosts, and in the stout acanthopod first and second cirri of *Poecilasma crassa* Gray, 1848 (see Young 2001, Figure 8), which attaches on and around the mouthparts of deep sea decapods where it grabs scraps of food as the host feeds. Despite these adaptations that make the koleolepadids well suited to their unusual diet of feeding on the tentacles of *Calliactis* (Yusa and Yamato 1999), the soft chitin of the naked peduncle and capitulum suggests that they would be vulnerable to the host's nematocysts.

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Two new species of box jellies (Cnidaria: Cubozoa: Carybdeida) from the central coast of Western Australia, both presumed to cause Irukandji syndrome

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ABSTRACT – Irukandji jellies are of increasing interest as their stings are becoming more frequently reported around the world. Previously only two species were known from Western Australia, namely *Carukia shinju* Gershwin, 2005 and *Malo maxima* Gershwin, 2005, both from Broome. Two new species believed to cause Irukandji syndrome have recently been found and are described herein. One, *Malo bella* sp. nov., is from the Ningaloo Reef and Dampier Archipelago regions. It differs from its congeners in its small size at maturity, its statolith shape, irregular warts on the perradial lappets, and a unique combination of other traits outlined herein. This species is not associated with any particular stings, but its phylogenetic affinity would suggest that it may be highly toxic. The second species, *Keesingia gigas* gen. et sp. nov., is from the Shark Bay and Ningaloo Reef regions. This enormous species is unique in possessing key characters of three families, including crescentic phacellae and broadly winged pedalia (Alatinidae) and deeply incised rhopalial niches and feathery diverticulations on the velarial canals (Carukiidae and Tamoyidae). These two new species bring the total species known or believed to cause Irukandji syndrome to at least 16. Research into the biology and ecology of these species should be considered a high priority, in order to manage their potential impacts on public safety.

KEYWORDS: *Malo bella*, *Keesingia gigas*, Ningaloo Reef, Indian Ocean, taxonomy

INTRODUCTION

Irukandji jellies are becoming of increasing interest to divers, swimmers, and occupational health and safety managers, as their stings are becoming more frequently reported around the world (Gershwin et al. 2013). Irukandji syndrome is a constellation of systemic symptoms with a delayed onset after a sting from a jelly. Symptoms typically include severe lower back pain, nausea and vomiting, difficulty breathing, profuse sweating, cramps and spasms, and a feeling of impending doom (Williamson et al. 1996). Some cases also have severe hypertension (high blood pressure), which can be life threatening. Two confirmed fatalities from Irukandji-related hypertension occurred in 2002 (Fenner and Hadok 2002; Huynh et al. 2003). It is generally believed that additional fatalities have occurred, but have been masked as heart attack, stroke, or drowning (Gershwin et al. 2009).

Irukandji are often associated with Queensland, as that is where the syndrome was discovered and named, and most of the research has occurred (Flecker 1952; Barnes 1964; Southcott 1967; Gershwin et al. 2013). However, the first unequivocal report of symptoms attributable to Irukandji syndrome in Australia occurred in Onslow in 1927 and 1928 (Stenning 1928). Much later, Macrokanis et al. (2004) demonstrated that Irukandji syndrome in Broome is at least as serious a problem as it is in Queensland. Two species of Irukandji jellies were described from Western Australia in 2005, namely *Carukia shinju* and *Malo maxima*, both from the far northwest near the town of Broome (Gershwin 2005b).

Farther south, reports of Irukandji are sparse. An unnamed species was identified from near the Montebello Islands in the region of Dampier (Gershwin 2005a), but lack of adequately preserved material prevented a full description and classification. In the Ningaloo Reef region, stings occur only occasionally, with 0–2 per year being typical (P. Hannay, Exmouth Hospital personal communication). These are not generally linked to specimens or species. Similarly, two Irukandji stings from unknown species have been reported in the Perth region, one at Scarborough Beach at a Surf Life Saving carnival in the 1980s and another near Rottnest Island in 2003 (Gershwin et al. 2009).

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Identification of these species is the first step toward understanding them and managing their stings.

It is therefore of potentially great importance to find another two new species of cubomedusae believed to cause Irukandji syndrome in Western Australian coastal waters. One, based on a specimen found near Exmouth following a cluster of 23 confirmed Irukandji stings (Gershwin and Hannay 2014), is similar to undescribed museum specimens from the Montebello Islands. Despite some variation, a conservative approach is taken herein and they are regarded as the same species, described as *Malo bella* sp. nov. below.

The other is based on an enormous specimen taken in a fishing net near Shark Bay in late summer 2012. This specimen poses a taxonomic puzzle, with some characteristics of the family Alatinidae and other characteristics more like the genus *Morbakka* in the family Carukiidae. This curious species is associated with systemic illness following a sting at Ningaloo Reef to the north. This species is here described as *Keesingia gigas* gen. et sp. nov.

Recently two methods of forecasting Irukandji jellies occurrence have been developed. One applies to species in the genus *Alatina*, which swarm on the 8th–10th nights after the full moon in Australia or the 9th–12th days after the full moon in Hawaii (Chiaverano et al. 2013). The other forecasting system applies to the diminutive *Carukia barnesi* in Queensland, which forms nearshore aggregations when the along-shore winds subside. The extent to which either of these new species may be predictable is currently unknown.

The purpose of this paper is to describe two new species of cubozoan jellies, presumed to cause Irukandji syndrome. This now brings the total number of Irukandji species described from Western Australia to four, with nine from Australia, and at least 16 globally. The biology and ecology of Irukandjis were recently reviewed (Gershwin et al. 2013) highlighting our paucity of knowledge on this remarkable group; these areas should be considered high priority for future study and safety management.

MATERIALS AND METHODS

All taxonomic observations and measurements were made on preserved material unless otherwise noted. Measurements were made with a ruler to the nearest mm or with Max-Cal digital calipers to the nearest 0.01 mm. Bell height (BH) was measured from the apex of the bell to the velarial turnover. Diagonal bell width (DBW) was measured across diagonal pedalia on a flattened specimen, at the height where the pedalium joins the exumbrella of the bell. Interrhopalial width (IRW) was measured between adjacent rhopalia, with the specimen flattened. Tentacle base width (TBW) was measured at the uppermost part of the tentacle, immediately below the pedalium. In opaque specimens, a search for phacellae was made by making a small incision in the upper corners of the bell, and then pulling back a small amount of mesoglea to expose the floor of the stomach, or by opening up the full length of the body wall to expose the stomach, and then opening the stomach in the same manner. In transparent specimens, absence of phacellae was obvious. Nematocysts were examined and measured with a Leica DMLB compound microscope and Leica IM-50 Image Manager v. 1.20 for Windows; all observations and photographs were made through a 40x objective (i.e. 400 x magnification). Nematocysts were identified following the keys of Calder (1974), Mariscal (1971), Williamson et al. (1996), and Gershwin (2006).

Abbreviations used. Western Australia (WA); Western Australian Museum, Perth (WAM); Museum and Art Gallery of the Northern Territory (NTM); Western Australian Department of Parks and Wildlife (DPaW); Marine Information and Research Group, Perth, Australia (MIRG Australia).

SYSTEMATIC RESULTS

Class Cubozoa Werner, 1973

Order Carybdeida Gegenbaur, 1856 (sensu Werner, 1984)

Family Alatinidae Gershwin, 2005

Genus *Keesingia* gen. nov.

http://www.zoobank.org/urn:lsid:zoobank.org:act:A94C930A-4641-4CED-ABFF-DA3876A78A2A

TYPE SPECIES

Keesingia gigas sp. nov.

DIAGNOSIS

Alatinidae with a large, thick, warty bell; with deeply incised frown-shaped rhopalial niches, divided below at the midline; with well developed subumbrellar mesenteries; with adradial gelatinous lappets.

REMARKS

The type species of the genus, *Keesingia gigas*, is remarkable, in many ways resembling *Morbakka* (Gershwin 2008) while also strongly resembling species in the Alatinidae (Table 1). For example, the rhopalial niche most resembles that of *Morbakka* or *Tamoya* with the deep cavity and dumbbell-shaped ostium (Bigelow 1938: text-fig. 20; Gershwin 2008: figs. 2D, E), and yet it also has a superficially split lower scale (Figure 2A herein), which is not found in any other cubozoan but suggests an affinity with *Alatina,* in which the lower scale is fully split, creating a T-shaped ostium (Bigelow 1938: text-fig. 11; Gershwin 2005c: fig. 2B; Bentlage 2010: fig. 1C). The ostium of the holotype of *Alatina grandis* (Agassiz and Mayer, 1902) figured by Bentlage (2010) is of the 'normal' *Alatina* type, that is to say, it is fully and prominently T-shaped, whereas the ostium of

TABLE 1 Comparison of characters of large-bodied species in the Carybdeida.

	Morbakka (Carukiidae)	*Tamoya* (Tamoyidae)	*A. grandis* (Alatinidae)	*Keesingia*
Bell	Large, thick, warty	Large, thick, warty	Large, thick, not warty	Large, thick, warty
Rhopalial niche	Dumbbell-shaped, lower undivided	Dumbbell-shaped, lower undivided	T-shaped with lower strongly divided	Dumbbell-shaped, lower divided
Rhopalial horns	Present	Absent	Absent	Absent
Pedalia	Narrow -winged	Narrow-winged	Broad-winged	Broad-winged
Pedalial canal	Spike at bend, quadrate, flared at end	Spike at bend, quadrate, flared at end	Without spike, flat, not flared	Without spike, flat, not flared
Stomach	Voluminous	Voluminous	Small, short	Small, short
Phacellae	Absent	Vertical	Broadly crescentic	Broadly crescentic
Mesenteries	Robust, flap-like in upper half, cord-like in lower half	Robust, flap-like in upper half, cord-like in lower half	[not described]	Flap-like in upper half, absent in lower half
Velarial canals	Feathery, diverticulated	Dendritic, diverticulated	Short, tree-like	Feathery, diverticulated
Perradial lappets	Present	Absent	Absent	Absent
Frenula	Single, hollow	Double	Well developed	Broad, hollow

Keesingia is shallow and more comparable to a smile with a hairlip or a very flat Q, where the split is so minor as to not disturb the integrity of the deep cavity. Another feature suggesting an alatinid affinity is the lack of rhopalial horns, whereas these structures are present in *Morbakka* and other carukiids (Gershwin 2005a; Gershwin 2008).

The warty bell would appear to place it firmly with *Morbakka* (Gershwin 2008), while its tall, barrel-like shape is more characteristic of *Alatina* (Figure 1; Gershwin 2005c). So too, its crescentic phacellae place it firmly within the Alatinidae (Gershwin 2005c). However, while the pedalia are clearly of the large-winged *Alatina* type, the velarial canals are clearly of the feathered *Morbakka* type, but the perradial lappet, so prominent in the latter taxon, is lacking.

The mesenteries are worthy of discussion. Large species such as *Morbakka* and *Tamoya* have well developed mesenteries developed along the sides of the stomach and connecting to the subumbrella (Gershwin 2008; Collins et al. 2011). It appears that they may help keep the stomach centred and the mouth in place. *Keesingia* also has well developed mesenteries (Figure 2D); however, like the Alatinids, the stomach is very small. Therefore, the stomach is not stabilised by the mesenteries and they seem rather without purpose.

So too, the adradial gelatinous lappets (Figure 2C) are intriguing, as they had never been reported in any other species until they were formally described as 'velarial lappets' recently (Lewis et al. 2013). In general form, velarial lappets resemble the more familiar perradial lappets, which are essentially just triangular thickenings of the bell tissue extending out along the velarium, except that perradial lappets occur over the perradii, and velarial lappets occur between the perradii and interradii. Moreover, perradial lappets are conspicuous in the Carukiidae and Tamoyidae, whereas velarial lappets were found in the Alatinidae. Curiously, velarial lappets are also found in *Keesingia*, but they do not extend down onto the velarium as they do in *Alatina alata*.

Based on overall morphology, *Keesingia* seems to have more of the diagnostic traits of the Alatinidae than the Carukiidae. Characters such as the broadly winged pedalia, the crescentic phacellae, the divided lower rhopalial covering scale, the lack of rhopalial horns and perradial lappets, and the very small stomach are all consistent family features of Alatinidae, whereas characters such as the thick warty bell, mesenteries, broad frenula, and diverticulated velarial canals are found in some species of Carukiidae and not others and are also found in the Tamoyidae (Table 1).

However, recent 16S barcoding of the *Keesingia* holotype confirmed the specimen's closer affinities with the Carukiidae (O. Berry, CSIRO, unpublished data). The morphological and molecular confusion between these large species suggests that the suite of morphological characters currently used for species

differentiation in these Cubozoa may be inadequate to properly answer questions of species delineation.

The large specimens photographed at Ningaloo Reef in 1987 and 2013 appear to be attributable to *Keesingia* (Figure 3), as does another specimen photographed there in the 1990s (Marsh and Slack-Smith 2010: p. 53). The sizes, bell shape, pedalia shape, and conspicuous orange wartiness are similar, and the gonads of the smaller specimen appear to be immature, suggesting that the species can grow much larger. Curiously, neither the collected specimen nor any of the photographed specimens appear to have tentacles; whether it is a feature of the species that they are so fine as to be overlooked, or that they are genuinely lacking, or that it is mere coincidence that they have been broken off in all three, is unclear.

A swarm of ~10–15cm tall cubomedusae videotaped at Rowley Shoals on 9 September 2013 may also be attributable to this species (see Gershwin and Hannay 2014, figure 2). These medusae are tall like alatinids, but with robust, squared off bells like *Morbakka* and *Malo* in the Carukiidae. These are the very characters that one would expect for *Keesingia* of any size.

ETYMOLOGY

The genus name, *Keesingia*, is named to honour Dr John Keesing of CSIRO Marine and Atmospheric Research, who not only provided the holotype for this species, but has been of great assistance and inspiration to the author for nearly 20 years.

Keesingia gigas **sp. nov.**

Figures 1–3

http://www.zoobank.org/urn:lsid:zoobank.org:act:801E03E8-634D-41C1-B72B-C4D33447E84A

MATERIAL EXAMINED

Holotype

WAM Z27970, 5 nm west of Cape Inscription, Dirk Hartog Island, Shark Bay, Western Australia, 25°36′28″S, 112°51′54″E, J. Keesing, 7 May 2012, hand held scoop net; immature specimen, 19 cm BH, 97.65 mm DBW, 49.44 mm IRW, 4.39 mm TBW.

OTHER MATERIAL EXAMINED

Photograph of specimen, Black Rock, Ningaloo Reef, Western Australia, P. Baker (WAM), 31 March 1987; approx. 50 cm BH; caused systemic sting reaction. Photograph of specimen, Ningaloo Reef, Western Australia, G. Taylor (physician in Busselton); did not cause systemic reaction. Photograph of specimen, Ningaloo Reef near Coral Bay, Western Australia, J. Totterdell (MIRG Australia), 12 April 2013; approx. 20 cm BH, 8–9 cm wide; recorded during dense bloom of *Crambione mastigophora*. No specimens retained.

DIAGNOSIS

Alatinidae with a large, thick, warty bell; with deeply incised frown-shaped rhopalial niches, divided below at the midline; with well developed subumbrellar mesenteries; with adradial gelatinous lappets.

DESCRIPTION

Holotype (from preserved specimen and photographs of live specimens)

Bell very tall and narrow (Figure 1), with rigid jelly about 9 mm thick around middle portion of bell. Exumbrellar surface fairly densely and evenly covered with thousands of small gelatinous warts over most of the body except for inside the corner furrows; the warts do not appear to be studded with nematocysts, nor do they appear to be abraded. Corner furrows well defined, moderately deep, running the full length of the bell from just below the apex to the top of the pedalia.

Pedalia short, with broad inner and outer wings, each more than the width of the pedalial canal; wings warty and fragile in life, largely abraded away in the preserved specimen. Pedalial canal flat, simple, about 7.5 mm wide proximally, tapering to half its width at the tip. Pedalial canal bend without a thorn or other adornment; flaring only slightly at distal end, and also flared slightly about 2/5 of the way toward distal end. Tentacles missing in this specimen, presumably lost during netting.

Rhopaliar niches very deeply incised into the bell. Ostium strongly dumbbell-shaped with a shallow vertical split at the midline of the lower covering scale (Figure 2A). Rhopalia uninterpretable due to degradation of the specimen. Rhopaliar horns lacking. Rhopaliar windows nondescript. Nerve cord pronounced, running from behind rhopalium down to base of pedalium, back up to rhopalium, and so forth.

Velarium with three gelatinous ‘lappets’ on the adradii of the exumbrellar side in each octant extending down onto the proximal edge of the velarium, as if overhanging it; these lappets are sculpted out of the mesoglea but are not connected with velarial canals (Figure 2C). On the subumbrellar side, approximately five canal roots extend onto velarium, all dendritic with first and second order diverticula, branching irregularly into about 6–9 canals reaching margin, all heavily diverticulated and appearing almost feather-like (Figure 2B). Perradial lappets lacking. A broad, hollow frenulum marks each perradius.

Phacellae broadly crescentic in the stomach corners; each with dozens of long, fine cirri, some distally bifurcated. Stomach small, short. Mesenteries well developed in upper fourth of subumbrellar interradii, about twice the length of the lips (Figure 2D). Lips folded, with smooth margins, only extending to about 1/8 the length of the subumbrellar cavity (Figure 2D).

Gonads: undeveloped in this specimen.

Colour: bell is transparent and colourless, somewhat

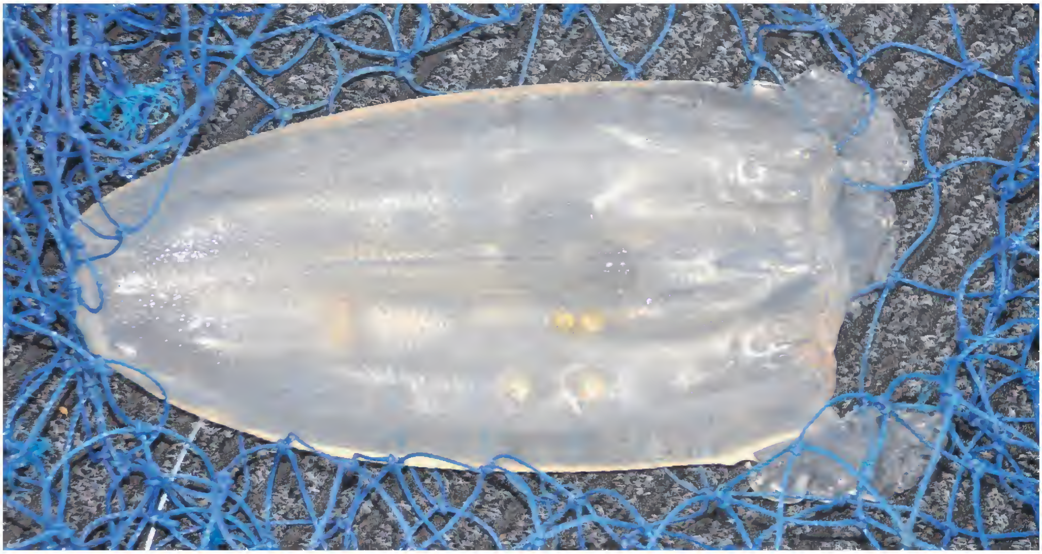

FIGURE 1 *Keesingia gigas* sp. nov., freshly caught holotype specimen; note orange warts densely scattered over body.

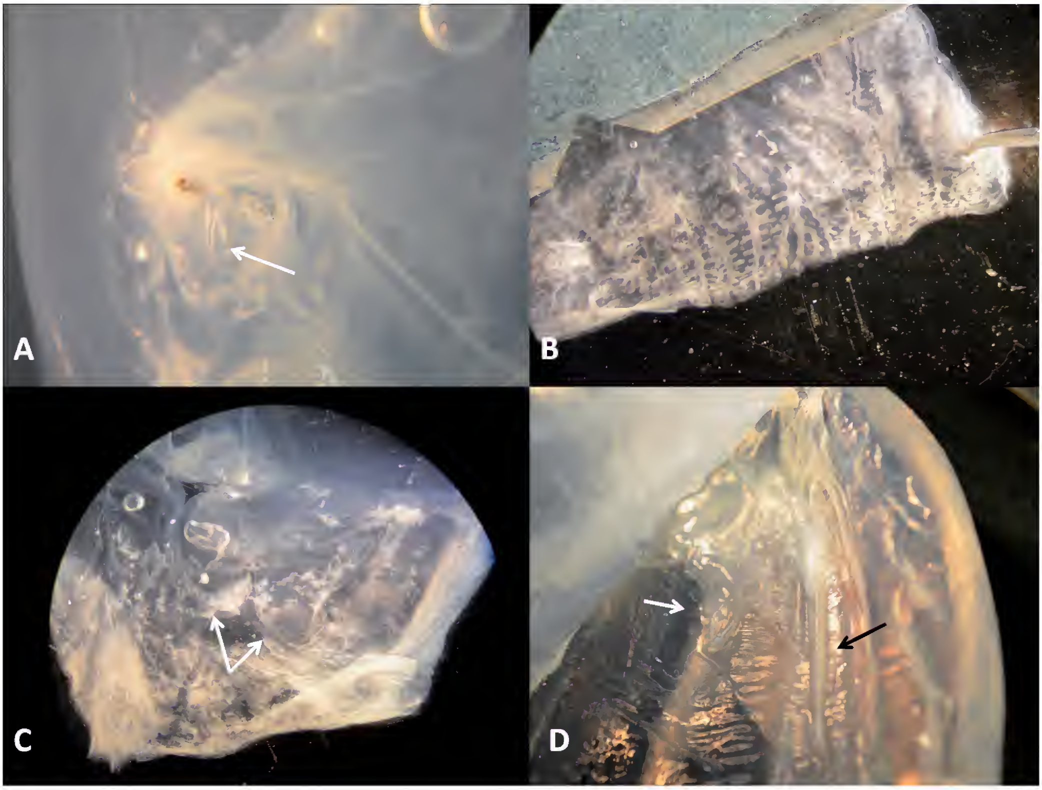

FIGURE 2 *Keesingia gigas* sp. nov., holotype. A. rhopaliar niche ostium; partially divided lower covering scale is indicated by arrow. B. velarial canals; note diverticula. C. adradial gelatinous lappets, indicated by arrows. D. mesenteries, indicated by black arrow; mouth is visible to the upper left (white arrow pointing to one lip).

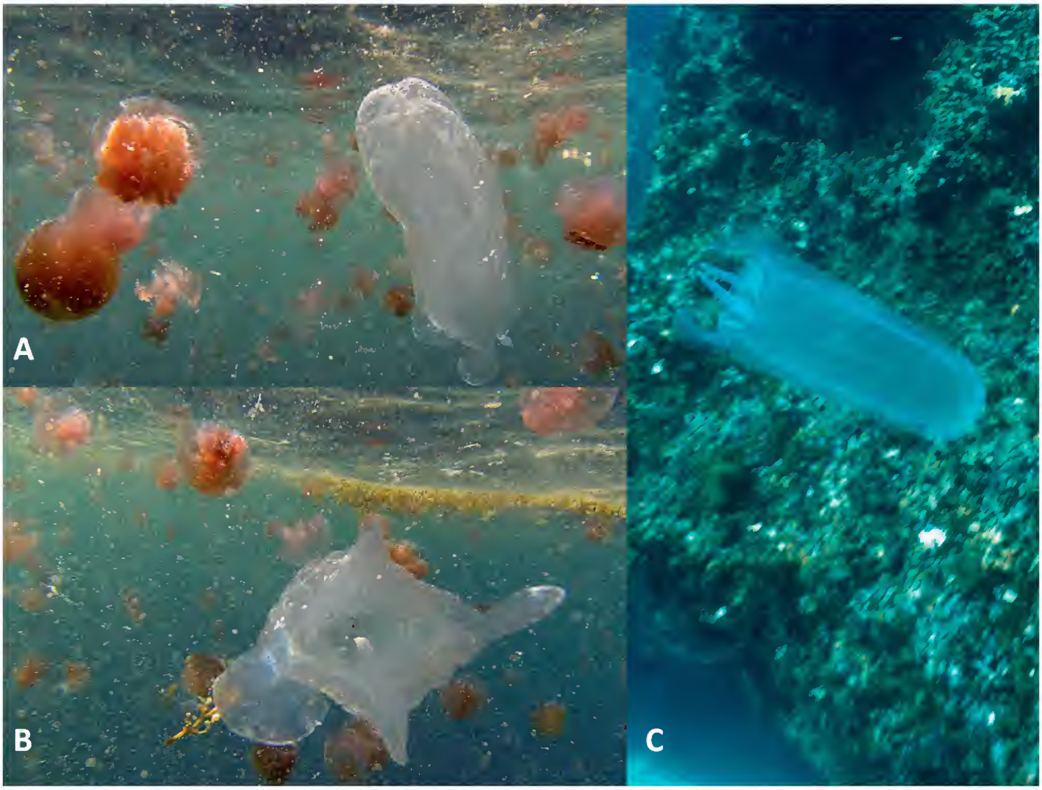

FIGURE 3 *Keesingia gigas* sp. nov., from Ningaloo Reef A, B. lateral view (A) and subumbrellar view (B) in bloom of *Crambione mastigophora* (sea tomatoes). (Image courtesy John Totterdell/MIRG Australia.) C. lateral view.

cloudy in appearance, with orange-coloured exumbrellar warts in life. Mesenteries and pedalial canals whitish.

Nematocysts: could not be found on the bell warts or pedalia.

TYPE LOCALITY

Dirk Hartog Island, Shark Bay, Western Australia, 25°36′28″S, 112°51′54″E.

DISTRIBUTION

Specimen confirmation exists only from the type locality. However, the photographs of large alatinids with orange warts at Ningaloo Reef in 1987 and in 2013 also appear to be attributable to this species, and a swarm of cubomedusae at Rowley Shoals on 9 September 2013 may be the young of this species (see Gershwin and Hannay 2014, Figure 2).

ETYMOLOGY

The species name, *gigas*, is in reference to the enormous size of this species.

ASSOCIATIONS

Three juvenile leatherjacket fish (family Monacanthidae) were captured with this specimen, living inside the subumbrellar cavity. While the tendency of young leatherjackets to shelter with medusae has been previously reported (Hutchins 1994), this is the first report of fish sheltering in an Irukandji species. Whether they were also preying upon it is unknown, as the specimen was thought to be already dead when captured.

STING REMARKS

Two cases of stinging by *Keesingia* (as *Tamoya gargantua*) were reported by Williamson et al. (1996: p. 242, and pl. 9.6A, B). One produced severe Irukandji syndrome, whilst the other caused only local and groin pain. These and two more cases of stinging by *Keesingia* (as *Alatina* sp.) were reported by Marsh and Slack-Smith (2010: pp. 52–55). Of these, one from Exmouth in 1978 was consistent with Irukandji syndrome, whilst the other from Ningaloo in 1995 involved only intense local and lymph pain.

Family Carukiidae Bentlage, Cartwright, Yanagihara, Lewis, Richards and Collins, 2010

Genus *Malo* Gershwin, 2005

Malo bella sp. nov.

Figure 4

http://www.zoobank.org/urn:lsid:zoobank.org:act:A4DE4BCD-C9D5-4683-901A-AABD532650C6

"Dampier Irukandji": Gershwin 2005a: Tables 2.1–2.12, 98, 103, 107, 119, 195, 201, Plate 4.7; Gershwin 2005b: 3, 20; Gershwin 2007: 64, 65, Table 1.

Malo n. sp. A "Dampier Irukandji": Gershwin 2006: 10, Table 1, Plate 19 [note that the specimen noted "holotype" is now paratype NTM C14617].

"Undescribed species of *Malo* is known from the islands off Exmouth": Gershwin et al. 2013: 40.

MATERIAL EXAMINED

Holotype

WAM Z27971, approximately 300 m east of the sandy beach in front of Harold E. Holt Memorial Communications Base, Exmouth Gulf (estimated GPS coordinates from Google Earth: 21°53′28.37″S, 114°08′57.47″E), R. De Jong (DPaW Parks and Visitors Services Coordinator), 9 July 2013, mid afternoon, 1–2 m below surface in 4–5 m total water depth; gravid female, 20.04 mm BH, 18.50 mm DBW, 10.96 mm IRW, 1.43 mm TBW.

Paratypes

NTM C14617, Trimoville Island, Western Australia, H. Larson, 21 April 1983, by nightlight at anchorage, on surface over 5 m, flat sandy bottom (20°24′S 115°34′E); 19.11 mm BH, 17.20 mm DBW, 8.35 mm IRW, 1.05 mm TBW with halo-like bands, male. NTM C5143, same data as C14617; 3 specimens, all mature but poorly preserved.

DIAGNOSIS

Malo with a very small body size at maturity; with long, well developed subumbrellar mesenteries; with one tri-branched velarial canal centrally located in each octant; perradial lappets broadly rounded, with irregular rows of nematocyst warts; rhopalial horns short and straight; statoliths almost perfectly hemispherical; tentacular nematocyst bands with or without halo-like shelves of tissue.

DESCRIPTION

Holotype

Body small, bell-shaped (Figure 4A), to about 19 mm BH, gravid at that size; with scattered nematocyst freckles, particularly lower on the bell near the velarium where they are slightly raised. Apex broadly rounded, nearly hemispherical; shallowly warted, lacking nematocysts. Bell of a robust consistency; evenly thick, with exumbrellar sculpturing of strongly defined pillars with shallow corner furrows, with rhopalial niches somewhat raised from the body wall.

Pedalia (Figure 4E) nearly half the bell height, unarmed, without nematocyst warts, freckles, or bars; scalpel-shaped, with a narrow abaxial wing c. 1x canal width, and broad adaxial wing c. 2x canal width; inner keel not overhanging at tentacle insertion. Pedalial canal simple, slightly diamond-shaped in cross section throughout length; bend with slight upward-pointing nub forming 90° corner; not flared at tentacle insertion. Tentacles four, one per pedalium, with a straight base, round in cross section; largely broken off in this specimen, but appearing more or less evenly banded, not of the halo form.

Gonads paired, leaf-like, nearly touching in midline halfway down bell; connected along entire length from stomach to velarium; narrower around and below rhopalium, pendant below rhopalium.

Velarial canals comprising one root per octant branching into three, one or two of which further branch; without lateral diverticula; without warts over the canals. Perradial lappets broadly rounded, tongue-shaped, nearly reaching velarial edge; with an irregular row of warts on each side (Figure 4C), without diverticula. Frenulum comprising a single simple sheet, lacking gelatinous buttresses, reaching about 3/4 the distance toward velarial margin, disappearing at rhopalium.

Rhopalial niche ostium frown-shaped, with a single well developed covering scale each above and below, broadly concave in shape (Figure 4C). Rhopalial horns relatively short, straight, evenly wide throughout their length, nearly vertical in orientation (Figure 4C). Rhopalial windows shallowly convex with a small indentation at the point where the rhopalial stem meets the body wall. Lower median lensed eye round, considerably larger than the dome-shaped upper median lensed eye. Lateral eye spots absent (Figure 4D). Statolith nearly perfectly hemispherical (Figure 4D).

Phacellae lacking. Stomach with numerous parallel folds, possibly indicating great expansion capabilities, or possibly sites of increased surface area for enzyme activity as would normally be found on the gastric phacellae. Mesenteries (Figure 4B) extremely well developed, fully webbed, with flaps extending down about ¾ the distance to the rhopalial niches, with a barely perceptible cord reaching the rhopalium, running through the center of a transparent strip of tissue. Manubrium cruciform, extending to about half the bell height; mouth with four short, broadly quadrate lips.

Colour: bell transparent and colourless, nematocyst warts faintly reddish, tentacles white, gonads nearly opaque whitish, eyes dark brown.

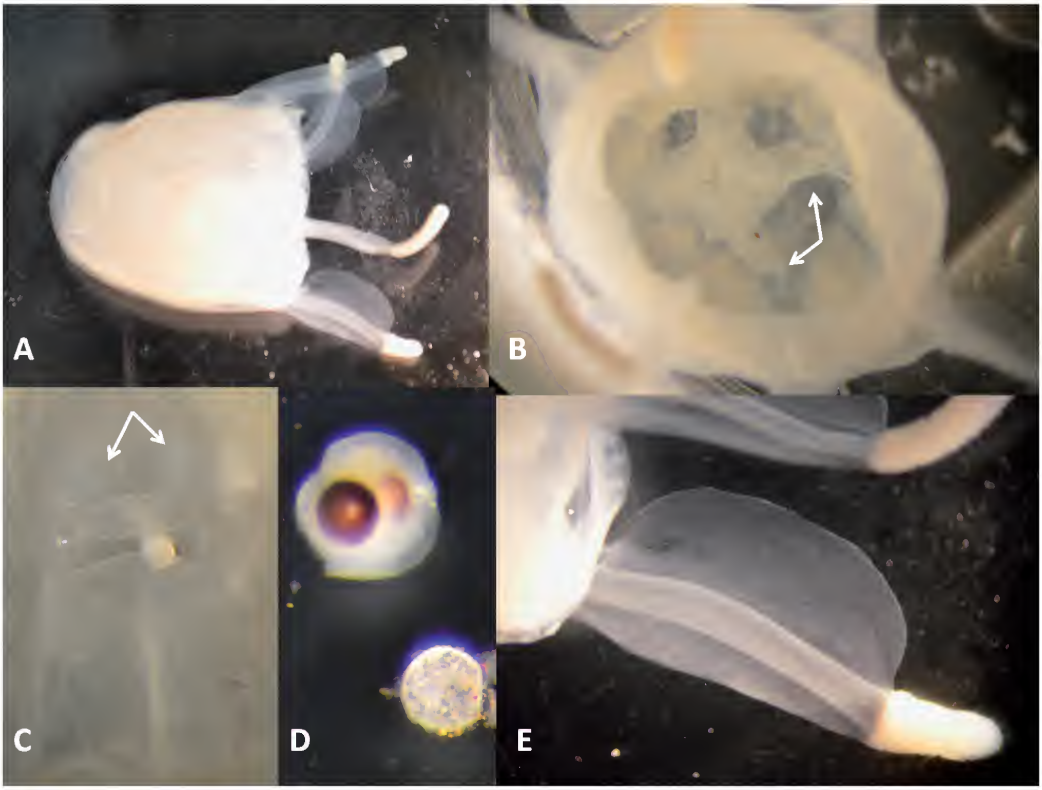

FIGURE 4 *Malo bella* sp. nov., holotype. A. habitus. B. subumbrellar view of mesenteries (indicated by arrows) and manubrium. C. rhopaliar niche (rhopaliar horns are indicated by arrows); note also perradial lappets with irregular nematocyst warts in lower centre of image. D. rhopalium (above) and statolith (below), dissected away from specimen and rotated such that left side of image would be 'down' in life; note absence of lateral eye spots. E. pedalium.

VARIATION

The paratypes have halo-form bands similar to those of some *Malo kingi* specimens, although the holotype does not. The origin and function of these bands remains unclear, as does the exact relationship of the banded and unbanded forms.

The velarial canals of paratype NTM C14617 were earlier interpreted as only two per octant, the adperradial widely bifurcated and the adinterradial narrow and simple (as "Dampier Irukandji" in Gershwin 2005a). These are now reinterpreted as three. However, the canals of this paratype have lateral diverticula whereas those of the holotype do not. One of the paratypes in lot NTM C5143 has a single main velarial canal root in each octant, with four finger-like canals issuing from it, each with numerous lateral diverticula, whereas the holotype has a single root with three canals and no diverticula. These differences are interpreted as intraspecific variation rather than specific distinction; similar canal variation is found in the confamilial *Morbakka* (Gershwin 2008).

The perradial lappets of paratype NTM C14617 are broadly rounded with large diverticula, and with a single large wart, whereas the holotype has an irregular row of warts on each side and lacks diverticulating canals.

ETYMOLOGY

The species name, *bella*, is in triple reference to its small bell-like shape, its beauty, and the Montebello Islands in the Pilbara region of Western Australia, where the species was first found. Noun in apposition.

TYPE LOCALITY

Approximately 300 m east of the sandy beach in front of Harold E. Holt Memorial Communications Base (estimated GPS coordinates from Google Earth: 21°53′28.37″S, 114°08′57.47″E), Exmouth Gulf, Western Australia.

ECOLOGY

Very little is known about the ecology of this species; however, the following details were noted at the time the holotype was collected:

- The specimen was moving/swimming in a northerly direction with outgoing tide past a coral bommie;
- Water temperature was reliably estimated at 19–21°;
- Many other plankton reported in the water at the same time including several individuals of another jelly that had same bell shape and size as the *Malo* specimen, four tentacles approx. 30–40 cm long and a very vibrant pink purple band around the base of bell.

DISTRIBUTION

Presently only confirmed from Exmouth Gulf and Trimoville Island in the Montebello Islands of the Pilbara region, WA. Photographs and video of *Malo* specimens taken along Ningaloo Reef and Coral Bay in 2013 appear to be attributable to this species, but are unverified.

NEMATOCYSTS AND STING POTENTIAL

The tentacular nematocysts of paratype NTM C14617 were figured by Gershwin (2006: pl. 19), with the following features: rice-shaped sub-ovate microbasic *p*-mastigophores: 31.67–40.47 x 14.01–16.50 µm (n = 19). The cnidome of the holotype was not studied.

The sting potential of this species is not yet known; however, because of its phylogenetic relationship to *M. kingi*, which is apparently lethal (Gershwin 2007), and *M. maxima*, which also causes severe Irukandji syndrome (Gershwin 2005b; Li et al. 2011), this species should be regarded as potentially dangerous.

REMARKS

Malo bella is the smallest species yet described in the genus. It is most similar overall to *M. kingi* (Table 2), in that both have a warty domed body, a 90° pedalial canal bend, short broad rhopaliar horns, and a single palmate velarial canal root. However, the two species differ in several structural features. First, *M. kingi* has warts over the velarial canals, whereas *M. bella* does not. Second, the pedalial wings are broader relative to the pedalial canal in *M. kingi* than in *M. bella*, and some specimens of the former have nematocyst freckles, whereas *M. bella* does not. Third, the statolith of *M. kingi* is globular with a prominent apical hook, whereas that of *M. bella* is almost perfectly hemispherical. Finally, *M. bella* is smaller at maturity (20 mm): specimens of *M. kingi* at the same size are immature.

The halo-form tentacle armament is worthy of discussion. Both *M. kingi* and *M. bella* have it, whereas this feature is not known in other species. Whether this represents ontogenetic change or unelucidated phylogenetic distinction or mere individual variation is not clear.

The asymmetrical occurrence of the perradial lappet nematocyst warts are curious. In specimen NTM C14617, these warts occur on the animal's left side of the lappets only, though the warts in the holotype occur asymmetrically on both sides; in the poorly preserved other paratypes, the velarium could not be examined adequately to determine their wart arrangement. Velarial warts are typically either symmetrical on the lappets (e.g. *Gerongia rifkinae* and *Malo kingi*, in which the warts occur in rows on both lappets), symmetrical on the velarial canals (e.g. *Carukia barnesi*, in which the warts occur in a patterned manner on the canals only), or completely random (e.g. the *Morbakka* species complex,

TABLE 2 Comparison of main diagnostic characters of species in the genus *Malo*. Abbreviations: Pedalial canal bend (PCB); rhopalial horns (RH); velarial canals (VC); perradial lappets (PL); mesenteries (MS).

Species	Body	Pedalia	Rhopalia	Velarium
Malo maxima	≈ 50 mm BH, warty, with flattened apex; moderate MS	3 nematocyst freckles; PCB with short blunt oblique projection	RH short, thick, straight; statolith globular with basal indentation	VC 1 root, 4 canals, 4-6 tips; PL with one wart
Malo kingi	≈ 30 mm BH, warty apically, with domed apex; large MS	With or without nematocysts; PCB 90°	RH short, broad, curved inward; statolith globular with basal indentation and apical tooth	VC 1 root, palmate, 4-5 tips; PL with 2 rows of 3-4 patches
Malo filipina	≈ 40 mm BH, warty, large MS	1 row of round warts; PCB with 'spike'	RH short, broad, blunt; statoliths unknown	VC palmate, 3-4 tips; PL with 2 rows of 2-4 warts
Malo bella sp. nov.	≈ 20mm BH, warty, with domed apex; large MS	Lacking nematocysts; PCB 90°	RH short, thick, straight; statolith nearly perfectly hemispherical	VC 1 root, 3-4 canals, ca 6 tips; PL with 2 irregular rows of warts

in which the warts are scattered among lappets, canals, and intermediate tissues). In this current case, the arrangement of warts is inconsistent with those known thus far.

ACKNOWLEDGMENTS

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The millipede genus *Antichiropus* (Diplopoda: Polydesmida: Paradoxosomatidae), part 2: species of the Great Western Woodlands region of Western Australia

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ABSTRACT – The species of the millipede genus *Antichiropus* found in the Great Western Woodlands region of southern Western Australia are reviewed, and 30 new species are described. The new species are: *A. alastairi, A. alatus, A. anconus, A. axicius, A. baudini, A. buchanorum, A. cavernus, A. cincinnus, A. cuspis, A. digitatus, A. equinus, A. exclamatus, A. framenaui, A. giganteus, A. howardi, A. incomptus, A. inflatus, A. inopinatus, A. kealleyi, A. lacustrinus, A. laticlavius, A. nadineae, A. paracalothamnus, A. rex, A. sagittulus, A. saxatilis, A. serratus, A. simpulus, A. succedaneus* and *A. westi*. This raises the number of known species in the genus to 39, with most of the new species having ranges less than 10,000 km^2, thus qualifying as short-range endemics.

KEYWORDS: new species, taxonomy, biodiversity, short-range endemics

INTRODUCTION

The Great Western Woodlands is unique because it is the largest area of relatively undisturbed Mediterranean climate woodlands in the world, occupying c. 160,000 km^2 in the south west region of Western Australia (Watson et al. 2008) (Figure 1). The region supports extraordinary species richness and may be considered a so-called biodiversity 'hotspot'. Field studies have shown that although insects and arachnids are the most numerous and diverse of the invertebrate groups in the area, millipedes, and in particular, species belonging to the paradoxosomatid genus *Antichiropus* Attems, 1911, are a remarkably diverse group in the region.

The taxonomic history of the genus *Antichiropus* is surprisingly short (Nguyen and Sierwald 2013). The genus was described by Attems (1911) for seven species collected in southwestern Australia by W. Michaelsen and R. Hartmeyer during the Hamburger südwest-australischen Forschungsreise of 1905. The descriptions and the accompanying illustrations of the gonopods were quite detailed, and sufficient to recognise each taxon. Verhoeff (1924) added the subgenus *Antichiropus* (*Solaenodolichopus*) (spelled *Solänodolichopus*) for three Queensland taxa, *A.* (*S.*) *teres* Verhoeff, 1924, *A.* (*S.*) *vittatus* Verhoeff, 1924, and *A.* (*S.*) *vittatus dorsalis* Verhoeff, 1924, but *Solaenodolichopus* was later recognised as a distinct genus by Verhoeff (1928). Another subgenus, *Antichiropus (Haplochiropus)* was proposed by Attems (1944) for *A. (H.) pustulosus* Attems, 1944 from New Guinea, but it too was raised to generic level by Jeekel (1968).

The next *Antichiropus* species wasn't described until nearly 70 years after Attems' pioneering work, with the establishment of *A. mammillifer* Jeekel, 1982 from the Eyre Peninsula, in South Australia (Jeekel 1982). This was followed a decade later by *A. humphreysi* Shear, 1992 from cave habitats in North West Cape, Western Australia (Shear 1992). The most recent publication – the first part of this series – included a new diagnosis of the genus and redescriptions of the nine previously named species (Car et al. 2013).

http://www.zoobank.org/urn:lsid:zoobank.org:pub:C8DF01E7-83BB-4231-B93D-5AB8945F6DE2

Despite the fact that, to date, only nine species have been formally described, the genus has been extensively collected and examined, and is known to consist of c. 160 species, ranging across most of Western Australia south of the Kimberley region, from 22° to 33°S and from 117° to 127°E. This paper describes 30 new species of the genus *Antichiropus*, from the Great Western Woodlands region, and the area between its southern boundary and the south coast of Western Australia: the named fauna of the genus is thus increased to 39 species.

MATERIALS AND METHODS

All material examined for this study is preserved in 75% ethanol and lodged in the Western Australian Museum, Perth, Australia (WAM). Specimens were examined with Leica MZ6 and MZ16A stereo microscopes and the images generated with a Leica MZ16A automontage imaging system using Leica Application Suite Version 3.7.0 software. The method of image capture follows that of Car et al. (2013): images of whole specimens were generally captured first and then various body parts were removed for further imaging. As before, a set of images of each gonopod from four orientations was captured but, in this study, there are additional images for some species showing detail of the solenomere tip. Usually the holotype or paratype material was used to generate images. Descriptions were compiled with the software package DELTA (Dallwitz et al. 1999). Car et al. (2013) published a revised description of the genus *Antichiropus* in part 1 of this series: characters that define the genus are, therefore, excluded from species' descriptions, unless the characters of the species under consideration differ from the general generic description. The maps were generated with ArcMap version 9.3 (ESRI Inc.).

GONOPOD MORPHOLOGY

The labelling of the processes on the gonopod follows that adopted by Car et al. (2013) and, as before, has been undertaken for convenience, and not to suggest homologies with podomeres. For clarity, labelling has been standardized across all species in the genus. With this in mind, we have decided to re-label what was called the prolongation of the femur (prof) on *A. mammillifer* Jeekel, 1982 in Car et al. (2013) as a femoral process (fp1) separate from the main femoral process, in an attempt to simplify the comparison of *A. mammillifer* with other similar species from the Great Western Woodlands. If the prolongation of the femur is present, it occurs as an upright, pointed structure on the femorite

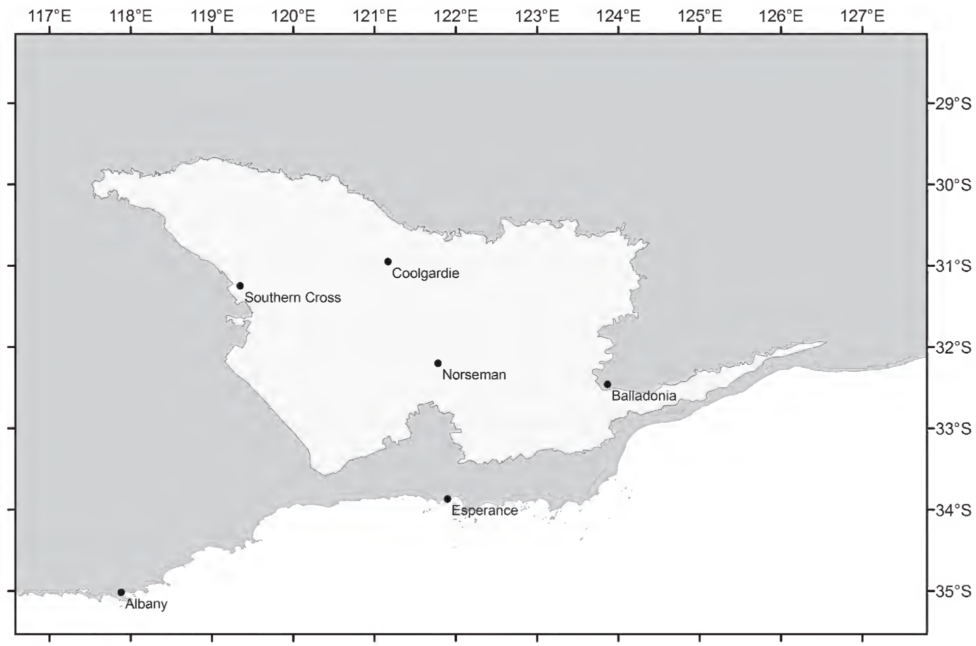

FIGURE 1 The Great Western Woodlands region of Western Australia.

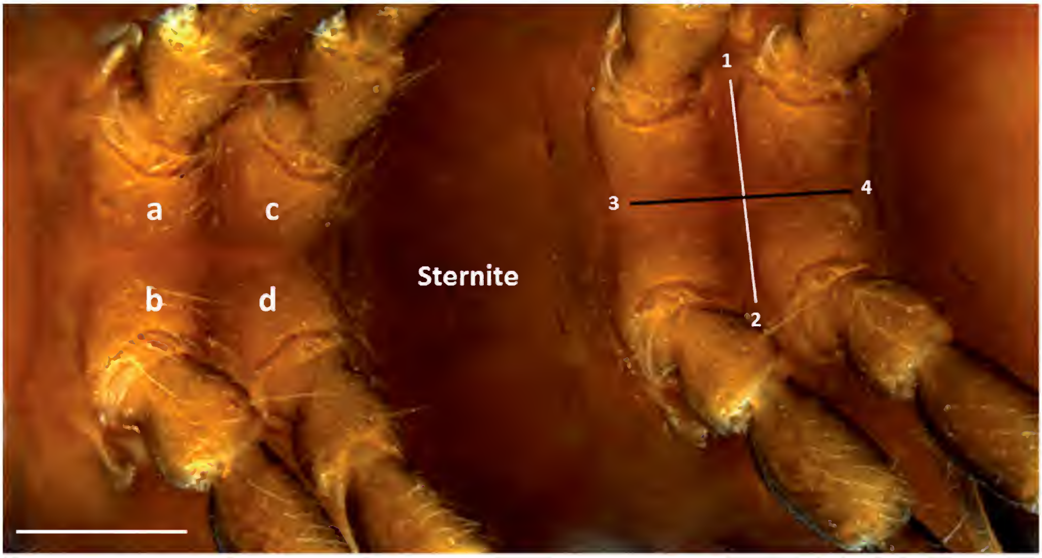

FIGURE 2 Midbody sternites of *Antichiropus exclamatus* sp. nov. (WAM T112932) showing cross impressions. Abbreviations: a–d, coxae of two pairs of legs. Line 1–2 transverse cross impression; line 3–4 longitudinal cross impression. Scale bar = 0.5 mm.

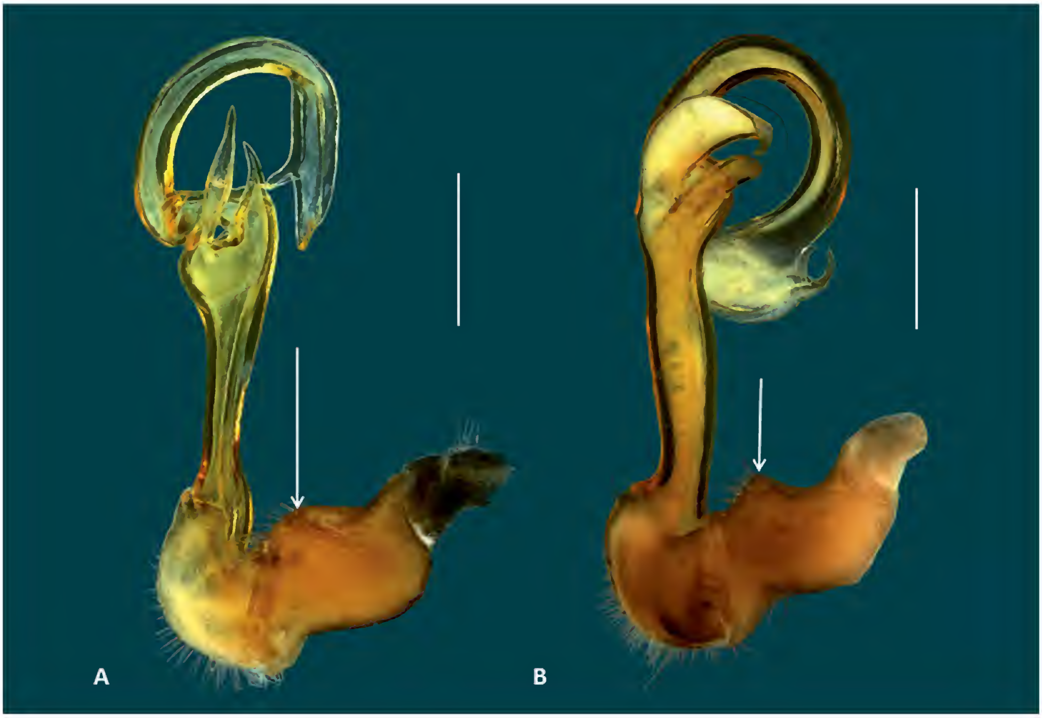

FIGURE 3 Lateral view of the left gonopods of two different *Antichiropus* species showing the coxal ridge on each (indicated by arrows): A, *Antichiropus axicius* sp. nov. (WAM T71835); B, *A. cavernus* sp. nov. (WAM T72020). Scale bars = 0.5 mm.

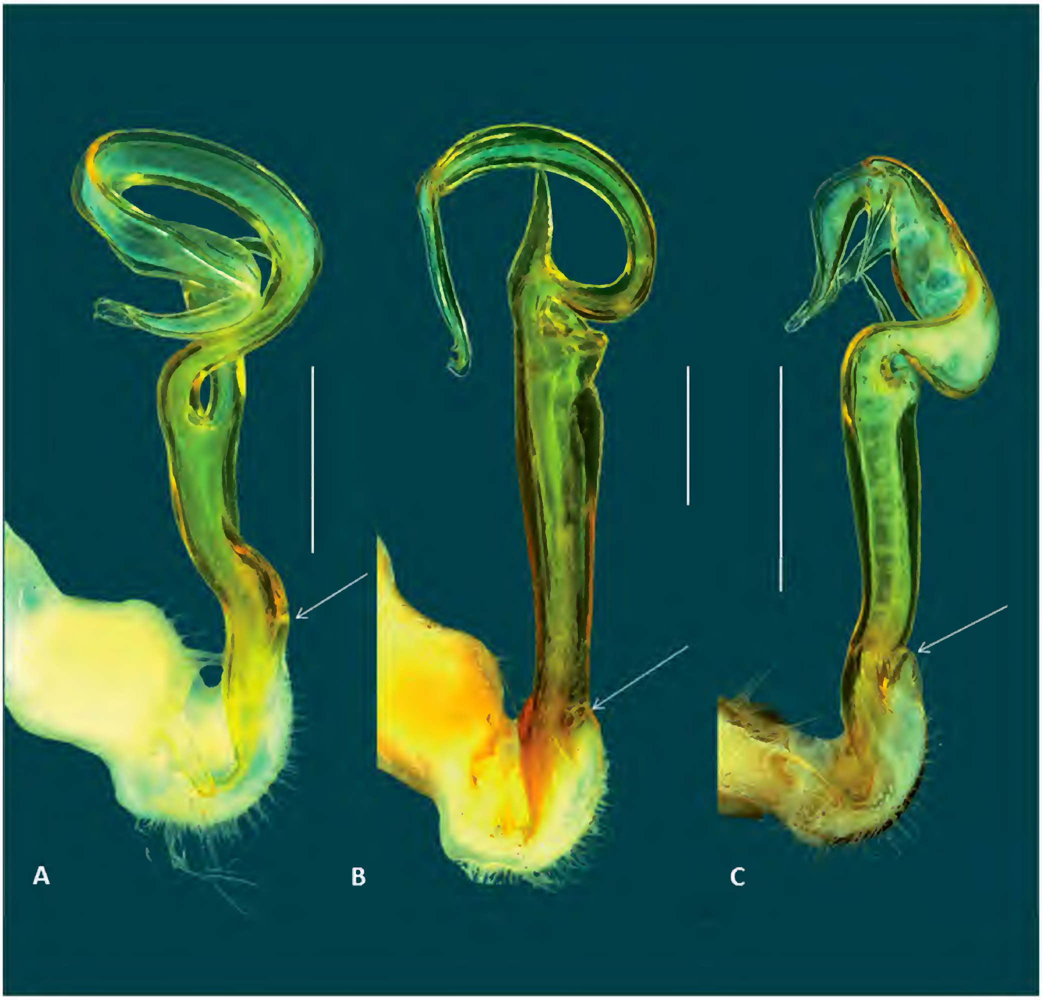

FIGURE 4 Medial view of the left gonopods of three different *Antichiropus* species showing the prefemoral lip on each (indicated by arrows): A, *Antichiropus cincinnus* sp. nov. (WAM T72055) showing virtually no lip; B, *A. alastairi* sp. nov. (WAM T42304) showing slight lip; C, *A. buchanorum* sp. nov. (WAM T115034) showing noticeable lip. Scale bars = 0.5 mm.

apex, just basal to the gonopod bending at right angles into the solenomere: the prof is best seen in medial view. It must be also noted that, as before, the main femoral process (MFP) is not numbered. Subsequent femoral processes are numbered fp1, fp2 etc. Thus, what is referred to in the text as fp1 is called the second femoral process.

It is also often difficult to decide how many processes are present on the solenomere of any species, particularly at the solenomere tip, where damage from mating or from collecting of specimens is common. There may be differing views on what constitutes a 'process' on the solenomere, but again, we have identified processes solely to assist with species identification and separation and, as before, have numbered them from solenomere tip to base.

For a full explanation of the labelling of the gonopods and explanatory diagrams of body parts refer to Car et al. (2013). In this paper, we have added a comparison of the distance between antennal sockets with the

widest part of the millipede face. We have also included explanatory diagrams of the following characters: sternal cross impressions (Figure 2); the gonopodal coxal ridge (Figure 3) as compared with the species *Antichiropus humphreysi* Shear, which has a prominent ridge (Shear 1992); and the gonopodal prefemoral lip (Figure 4). We have also added two more labels to those already used in identifying gonopod parts: stip = solenomere tip; and serr = serrations on the gonopod.

Females could only be identified positively as the same species as males in any area if they were collected with those males.

TAXONOMY

Order Polydesmida Pocock, 1887

Suborder Strongylosomatidea Brölemann, 1916

Family Paradoxosomatidae Daday, 1889

Tribe Antichiropodini Brölemann, 1916

Genus *Antichiropus* Attems, 1911

Antichiropus Attems 1911: 168.

TYPE SPECIES

Antichiropus variabilis Attems, 1911, by subsequent designation of Brölemann (1916).

DIAGNOSIS

See Car et al. (2013).

REMARKS

The new species described in this paper conform quite closely to the diagnosis of the genus *Antichiropus* recently presented by Car et al. (2013), and no change to the diagnosis is necessary.

Antichiropus alastairi sp. nov.

Figures 4B, 5, 35

http://www.zoobank.org/urn:lsid:zoobank.org:act:03ECB41F-EBC4-4463-9A78-1511F2266589

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia***: , Askew Road, site BE 6, 30°35′46″S, 117°54′28″E, 15 September 1998–8 April and 25 October 1999, wet pitfall traps, L. King (WAM T71834).

Paratypes

Australia: ***Western Australia***: 1 , Bunce Bin, 2 km N of Beacon, 30°27′S, 117°52′E, 28 June–26 July 1985, pitfall trap, B.Y. Main (WAM T42304).

Other material

Australia: ***Western Australia***: 1 , 2 juveniles, Mungarri Nature Reserve North, Beacon, site BE 12, 30°19′51″S, 117°45′12″E, 15 September 1998–8 April and 25 October 1999, P. Van Heurck (WAM T71863).

DIAGNOSIS

Gonopod: *Antichiropus alastairi* is similar to *A. framenaui* and *A. alatus* because each has an elongate ribbon-like solenomere carrying a small short process near its tip, and a long pointed second process in the apical third (Figures 5, 6 and 17). In addition, each has a conspicuous, large, pointed prolongation of the femorite. *A. alastairi* can, however, be distinguished by a relatively slender femorite and the irregular shape of the main femoral process (Figures 5C, D).

DESCRIPTION

Male holotype

Body c. 20 mm long; midbody ring c. 2 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 5A); leg colour as for body. No paranota on posterior rings (Figure 5B). Sternites without obvious processes/tubercles, sternal lamella broad, square. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks at least partially obscuring cardines when viewed face-on, maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively slender. Collum 1 x as long as head (in lateral view) (Figure 5A). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) similar in length to but more robust and thicker than femorite, with slight ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid, appearing to hug femorite base; femorite (F) c. 2/3 of acropodite length in situ, upright, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, irregularly shaped with a sharp point; second femoral process (fp1) absent; prolongation of femorite apex (prof) present, mainly upright, long, slender and sharply pointed; solenomere (S) long, forming >1 loop/circle, much more slender than femorite, and stoutest in basal half; solenomere tip with single flattened end and no serrations; solenomere process (sp1) near solenomere tip, small, pointed, upright, slender; second solenomere process (sp2) positioned c. halfway along solenomere, prominent, pointed (Figures 5C–F).

Female

The female specimen cannot positively be identified as *A. alastairi* as it was collected from a slightly different locality. It seems likely, however, that it is *A. alastairi* because it was collected very close by, is similar in colour to the male (chestnut brown) and of similar length, but slightly broader (c. 3 mm) when viewed dorsally (WAM T71863).

DISTRIBUTION

This species is known only from the Beacon area of the Great Western Woodlands (Figure 35).

ETYMOLOGY

This species is named in honour of Alastair Buchan, a person deeply dedicated to environmental protection.

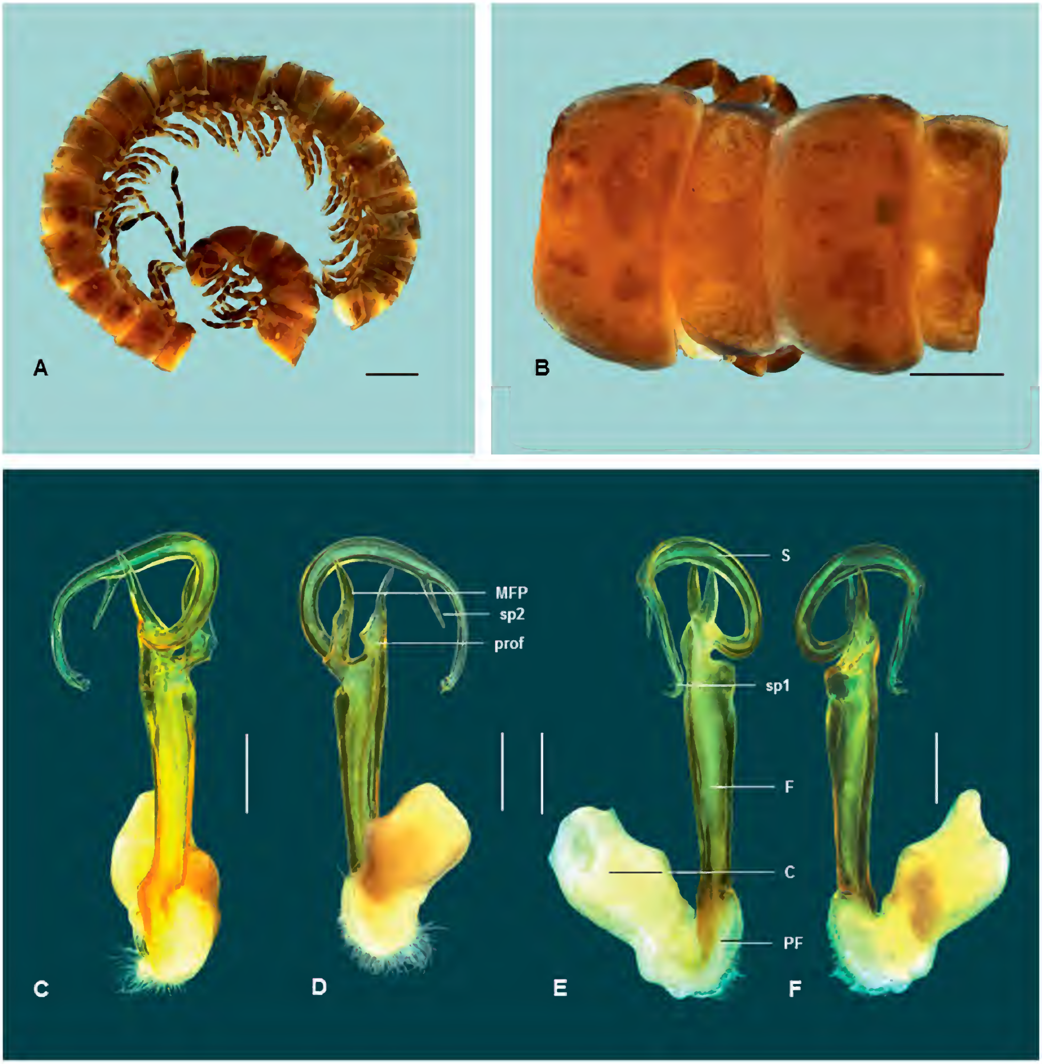

FIGURE 5 *Antichiropus alastairi* sp. nov.: A–B, paratype male (WAM T42304) habitus: A, lateral view; B, dorsal view; C-D, paratype male (WAM T42304), left gonopod: C, posterior view; D, anterior view; E-F, holotype male (WAM T71834); E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

Antichiropus alatus sp. nov.

Figures 6, 35

http://www.zoobank.org/urn:lsid:zoobank.org:act:ED207C3C-DB56-4A24-81D3-5BAF140B679D

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Mt Gibson Station, site 6, 29°43′35″S, 117°18′28″E, 20–31 August 2001, dry pitfall traps, bowgada/*Melaleuca* shrubland on deep red sands, Biological Survey (WAM T65516).

Paratypes

Australia: ***Western Australia*:** 1 , 1 , Mt Gibson Station, site 9, 29°41′13″S, 117°21′37″E, 20–31 August 2001, dry pitfall traps, mallee woodland on rocky red loamy clay, Biological Survey (WAM T65500); 1 , Mt Gibson Station, site B, 29°41′58″S, 117°24′11″E, 20–31 August 2001, dry pitfall traps, mallee woodland on white sandy clay, Biological Survey (WAM T65517); 1 , 1 , Mt Gibson Station, site 10, 29°41′07″S, 117°23′43″E, 20–31 August 2001, dry pitfall traps, York gum woodland on red loamy clay, Biological Survey (WAM T65518).

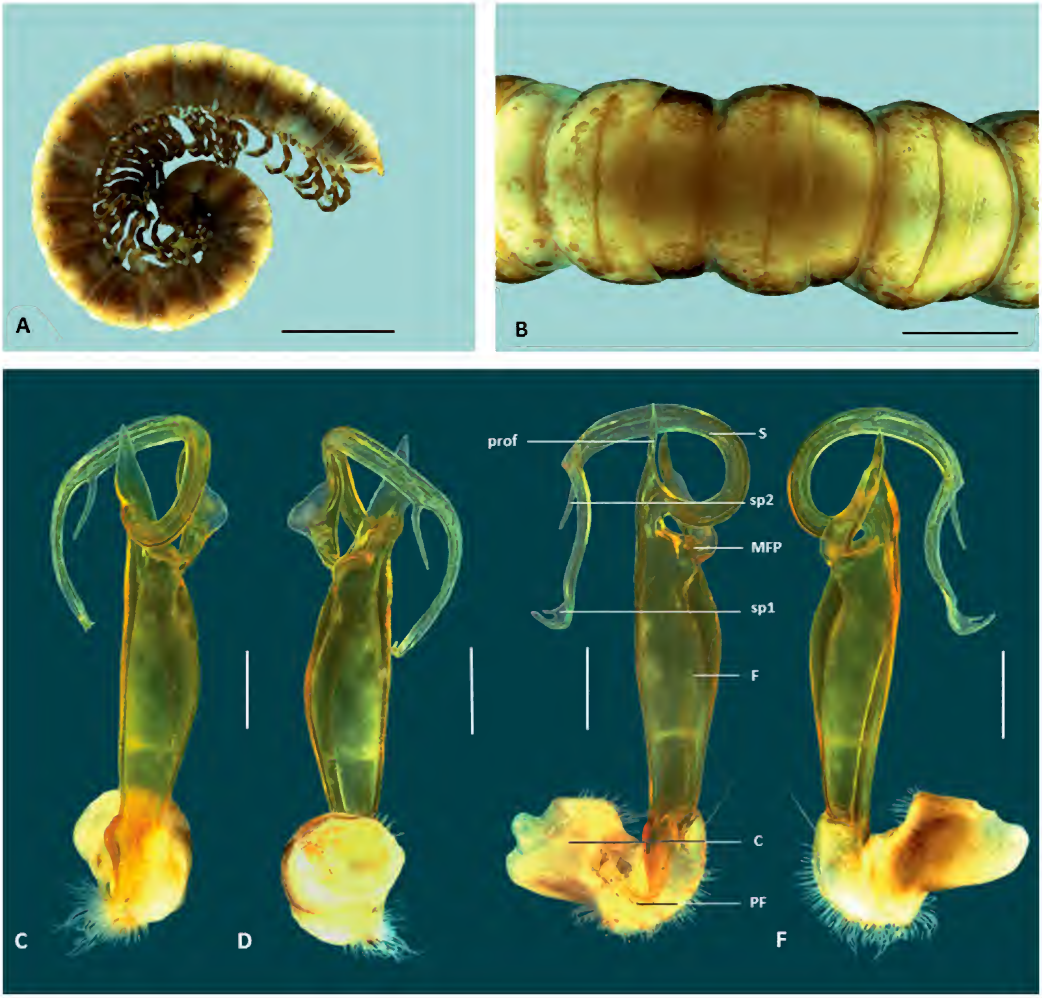

FIGURE 6 *Antichiropus alatus* sp. nov.: paratype male (WAM T65500) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 5 mm; B = 2 mm; C–F = 0.5 mm.

Other material

Australia: ***Western Australia*:** 1 , Mt Gibson Station at 29°37′12″S, 117°10′24″E, 27 September 2001, dead on ground, M.S. Harvey and B.Y. Main (WAM T65525); 1 , Mt Gibson Station at 29°36′38″S, 117°10′53″E, 27 September 2001, dead on ground, M.S. Harvey and B.Y. Main (WAM T65526); 1 , Mt Gibson iron ore mine at 29°35′59″S, 117°11′51″E, 10 May 2005, M.S. Harvey and S. Thompson (WAM T65527); 1 , Mt Gibson iron ore mine at 29°34′33″S, 117°09′38″E, 9 May 2005, under rock, M.S. Harvey and S. Thompson (WAM T65528); 1 , 1 , 1 juvenile, Mt Gibson iron ore mine at 29°34′33″S, 117°09′38″E, 10 May 2005, under rock, M.S. Harvey and S. Thompson (WAM T65529); 1 , Mt Gibson iron ore mine, banded ironstone ridge, Extension Hill west facing, 29°34′33″S, 117°09′38″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65532); 1 , Mt Gibson iron ore mine, banded ironstone ridge, Extension Hill west facing, 29°35′43″S, 117°11′14″E, 1–11 June 2005, wet pitfall traps, S. Thompson (WAM T65534); 1 , Mt Gibson iron ore mine, ironstone slopes, Extension Hill, east facing, 29°34′32″S, 117°09′49″E, 1–11 June 2005, wet pitfall traps, S. Thompson (WAM T65538); 1 , 3 juveniles, Mt Gibson Station, 29°26′18.4″S, 117°10′23.1″E, 21 August 2001, A. Baynes and R.D. Foster (WAM T73425); 1 , 1 , 2 juveniles, Mummaloo, c. 76 km NE. of Wubin, 29°40′16.00″S, 117°13′40.50″E, 4 July 2012, hand foraging, *Eucalyptus* and *Acacia* leaf litter, M.K. Curran and S.R. Bennett (WAM T125761).

DIAGNOSIS

Gonopod: *Antichiropus alatus* is most similar to *A. alastairi* and *A. framenaui,* but *A. alatus* can be recognised by the very stout, almost urn-shaped femorite (Figures 6C–F), the very long slender solenomere (Figures 6E, F) and by far the most robust and longest prolongation of the femorite, arising from a thick base (Figures 6C–F). The main femoral process is distinctly hatchet-shaped when viewed anteriorly (Figure 6D).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 6A), with broad pale dorsal stripe running full length of body (Figure 6B); leg colour as for body. No paranota on posterior rings. Sternites without obvious processes/tubercles, sternal lamella broad, square. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, the cardines and stipites clearly visible when the animal is viewed face-on, maximum width c. 3 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) similar in thickness to but shorter than femorite, with noticeable ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid, appearing to hug femorite base; femorite (F) c. 2/3 of acropodite length in situ, upright, thickest midway along its length, becoming slightly thinner towards its apex; main femoral process (MFP) stout and long (to c. 1/4 solenomere length), pointed, but not spine-like, broadly hatchet-shaped but with extended apex; second femoral process (fp1) absent; prolongation of femorite apex (prof) present, broad at base, long and pointed; solenomere (S) very long, extending in situ to 1/2 acropodite length, much more slender than femorite, generally tapering towards tip; solenomere tip with single slightly flattened end and no serrations; solenomere process (sp1) near solenomere tip, small, pointed, upright; second solenomere process (sp2) positioned c. halfway along solenomere, prominent, pointed, long and slender (Figures 6C–F).

Female

Of similar colour and general appearance to the male but slightly broader (c. 3 mm) when viewed dorsally (WAM T65500).

DISTRIBUTION

This species has been collected only from Mt Gibson Station (Figure 35).

ETYMOLOGY

This species' name refers to the greatly enlarged prolongation of the femorite on the male gonopod (Latin, adjective, *alatus,* winged).

***Antichiropus anconus* sp. nov.**

Figures 7, 35

http://www.zoobank.org/urn:lsid:zoobank.org:act:FFB4C798-E678-4518-AE29-2849AEF77EF4

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia***: , Buldania Rocks, Eyre Highway, 32°04′43.4″S, 122°02′02.8″E, 2 August 2012, under rocks on granite outcrop, J.M. Waldock (WAM T126106).

Paratypes

Australia: ***Western Australia***: 1 , National Highway, 110 km NW of Balladonia, 32°01′08″S, 122°50′14″E, 23 July 2007, in damp mallee litter, C.A. Car (WAM T112937); 1 , collected with paratype (WAM T112938).

Other material

Australia: ***Western Australia***: 3 juveniles, National Highway, 110 km NW of Balladonia, 32°01′08″S,

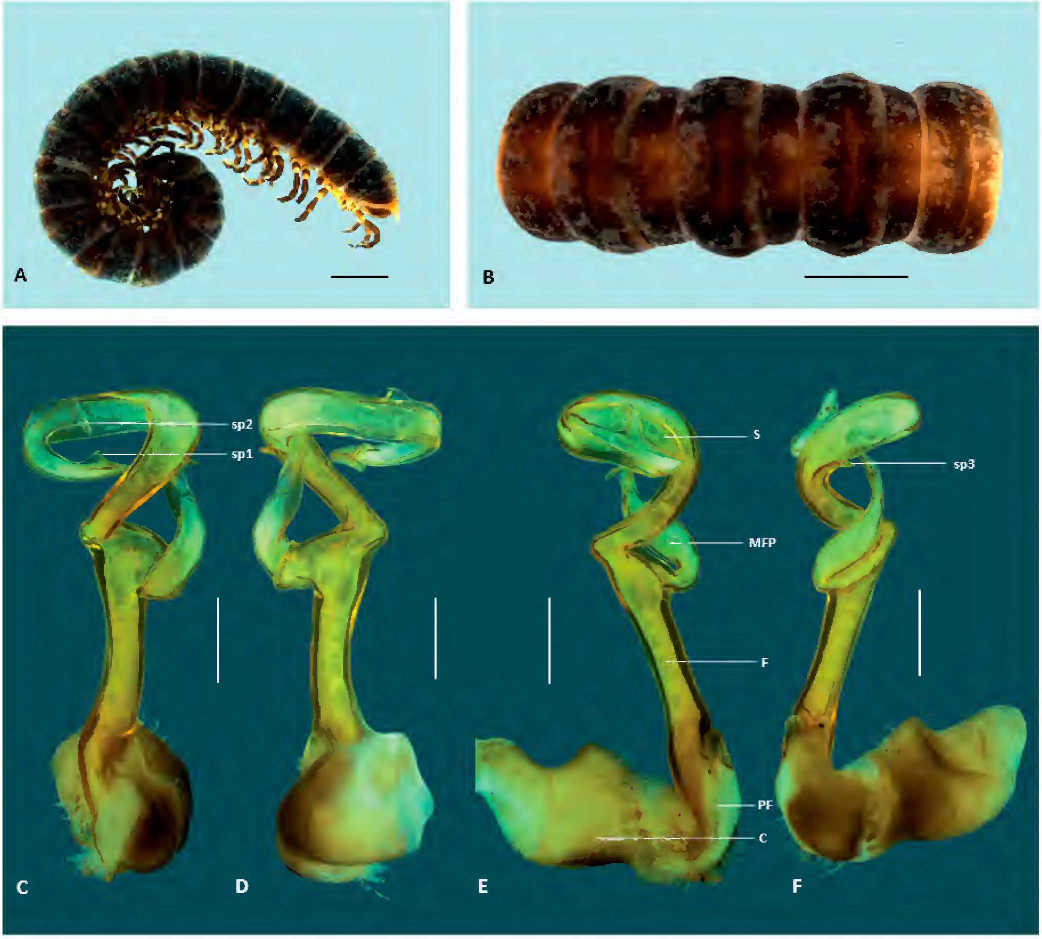

FIGURE 7 *Antichiropus anconus* sp. nov.: paratype male (WAM T112937) habitus: A, lateral view; B, dorsal view; C-F, left gonopod holotype male (WAM T126106): C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, sp2 and sp3, solenomere processes 1, 2 and 3. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

122°50′14″E, 23 July 2007, in damp mallee litter, C.A. Car (WAM T54244); 1 , Woodline, 31°48′S, 122°19′E, 1 August 1980, mallee/*Triodia*, debris, W.F. Humphreys (WAM T71828); 2 , remains, Buldania Rocks, c. 27 km NE of Norseman, N of Eyre Highway, 32°04′45.8″S, 122°02′16.0″E, 16 November 2011, under granite rocks in *Acacia* woodland, C.A. Car and J.M. Waldock (WAM T119062, T119063).

DIAGNOSIS

Gonopod: *Antichiropus anconus* may be separated from two other similar species, namely *A. inopinatus* (Figure 22) and *A. equinus* (Figure 15), by a distinctively shaped main femoral process, the lack of a second femoral process, the presence of three solenomere processes and lack of serrations on the solenomere, either at its base or tip. In addition, the second solenomere process has a distinctive L-shape (Figures 7C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown, almost black (Figure 7A); leg colour as for body. No paranota on posterior rings (Figure 7B). Sternites without obvious processes/tubercles, sternal lamella broad, square. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae;

face broad, cheeks at least partially obscuring cardines, when viewed face-on, maximum width c. 3.5 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than the proximal ones, and relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) similar in length but more robust and thicker than femorite, with noticeable ridge on anterior surface; prefemur (PF) somewhat shorter than femorite, with distinct process at clearly demarcated join of prefemur and femorite, noticeable prefemoral lip; femorite (F) contributing to c. 1/2 acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) stout, pointed, carried on large femoral protuberance at right angles to femorite, irregularly shaped; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) held in different plane from femorite, i.e. in Figure 7C, femorite is shown as vertical and solenomere appears orientated horizontally, long, forming >1 loop/circle, generally thicker than femorite, of variable thickness, thickest midway along length; solenomere tip with single flattened end and no serrations; solenomere process (sp1) near solenomere tip, small, pointed, triangular; second solenomere process (sp2) positioned c. halfway along solenomere, prominent, not pointed, L-shaped; third solenomere process (sp3) near solenomere base, small, pointed (Figures 7C–F).

Female

Of similar length, but slightly broader when viewed dorsally (c. 3 mm). The only female is, however, chestnut brown in colour with a broad, pale, dorsal stripe, which may be due to discoloration (WAM T112938).

DISTRIBUTION

This species has been hand collected from several sites along the edge of the Eyre Highway near Balladonia (Figure 35).

ETYMOLOGY

This species is named for the elbow-like shape of the main femoral process (Latin, noun, *anconus*, bend in the arm).

Antichiropus axicius sp. nov.

Figures 3A, 8, 36

http://www.zoobank.org/urn:lsid:zoobank.org:act:0EE6D464-D9BE-4302-B787-4A0AD7C7CA10

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*****:** , Mungarri Nature Reserve North, Beacon, site BE 12, 30°19′51″S, 117°45′12″E, wet pitfall trap, 15 September 1998–25 October 1999, P. Van Heurck (WAM T71835).

Other material

None.

DIAGNOSIS

Gonopod: both *Antichiropus axicius* and *A. lacustrinus* have noticeably short femorites and the main femoral process of each arises from a prominent broadening of the distal femorite. *A. axicius* has however, a longer less curved femorite than *A. lacustrinus*, a second femoral process that is roughly triangular when viewed anteriorly and of similar shape to the main femoral process (Figures 8C–F): *A. lacustrinus* has a much longer, more slender second femoral process and a more bulbous main femoral process (Figures 24C–F). The first solenomere process of *A. axicius* is large and prominent. *A. axicius* may also appear similar to *A. equinus* but has a much more noticeable thickening of the distal femorite and has femoral processes shaped differently from *A. equinus* (Figure 15).

DESCRIPTION

Male holotype

Body c. 20 mm long; midbody ring c. 1.5 mm wide, with distinct beaded waist, metazonite slightly wider than prozonite. Colour chestnut brown overall (Figure 8A); legs noticeably paler than general body colour. No paranota on posterior rings (Figure 8B). Sternites without obvious processes/tubercles, sternal lamella broad, helmet-shaped. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively robust. Collum 0.8 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) similar in length to but more robust and thicker than femorite, with slight ridge on anterior surface; prefemur (PF) somewhat shorter than femorite, appearing to hug femorite base, a small prefemoral lip; femorite (F) c. 1/2 of acropodite length in situ, slightly curved when viewed anteriorly, broadening into large rounded protuberance from which the MFP arises; main femoral process (MFP) short, <1/4 solenomere length, stout, pointed, hatchet-shaped; second femoral process (fp1) present, arising close to solenomere base, upright, pointed, short, triangular; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, generally as thick as femorite,

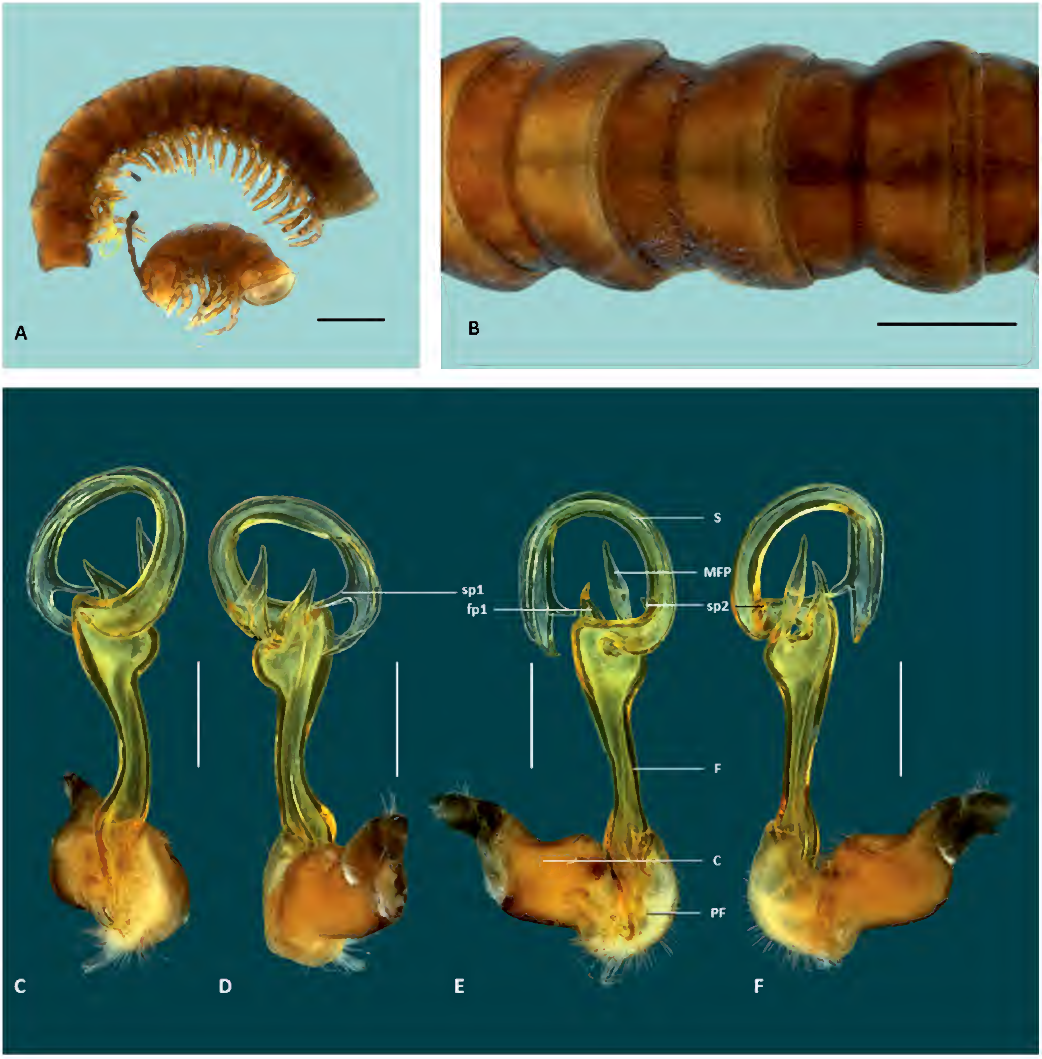

FIGURE 8 *Antichiropus axicius* sp. nov.: holotype male (WAM T71835) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

thick at base, becoming thinner midlength, thickening again at tip; solenomere tip single, square or flattened, with no serrations; solenomere process (sp1) in apical 1/3 of solenomere, prominent, pointed, upright, slender; second solenomere process (sp2) near solenomere base, prominent, pointed (Figures 8C–F).

Female

No females have been collected.

DISTRIBUTION

This species is known only from Mungarri Nature Reserve, but as only one specimen has been collected, its range is unknown (Figure 36).

ETYMOLOGY

This species is named for the shape made by the femorite processes when viewed anteriorly (Latin, noun, *axicia*, shears).

Antichiropus baudini **sp. nov.**

Figures 9, 35

http://www.zoobank.org/urn:lsid:zoobank.org:act:B0C2FD43-BBDD-41CB-BA01-C01F3C384F36

MATERIAL EXAMINED

Male holotype

Australia: ***Western Australia***: , Esperance, Wireless Hill, 33°52′44″S, 121°53′24″E, 3 June 2007, hand collected under rocks, M.L. Moir and K.E.C. Brennan (WAM T80691).

Paratypes

Australia: ***Western Australia***: 6 , 3 , Duke of Orleans Bay, Mt Belches southern side, site 4, 33°56′36″S, 122°33′42″E, 2 June 2007, hand collected under granite rocks, M.L. Moir and A. Longbottom (WAM T80694); 5 , 6 , Duke of Orleans Bay, Mt Belches near summit, site 1, 33°56′26″S, 122°34′31″E, 2 June 2007, hand collected under granite rocks, M.L. Moir and A. Longbottom (WAM T80703).

Other material

Australia: ***Western Australia***: 1 , Cape Arid National Park, Thomas River, 33°51′11″S, 123°01′00″E, 8

FIGURE 9 *Antichiropus baudini* sp. nov. male from Wittenoom (WAM T71874) A and C habitus: A, lateral view; C, dorsal view; B, holotype male (WAM T80691) left gonopod anterior view solenomere tip; D–G, left gonopod: D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; serr, serrations; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 0.2 mm; C = 1 mm; D–G = 0.5 mm.

June 2012, K.E.C. Brennan et al. (WAM T124575); 1 , 5 , 1 juvenile, Wittenoom, near junction with Dempster Road, site ES 4, 33°38′18″S, 122°00′50″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T71874, T71875); 1 , Backmans Road, near Burdett Road junction, SE. of Mt Burdett, site ES 9, 33°29′05″S, 122°14′27″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T71876); 16 , 7 , 4 juveniles, Brockway Rd, Helms Arboretum Reserve, site ES 2, 33°43′42″S, 121°47′50″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T71877); 1 , Shark Lake Rd, Helms Arboretum Reserve, site ES 1, 33°44′49″S, 121°48′55″E, 15 October 1999–1 November 2000, pitfall, P. Van Heurck et al. (WAM T71878); 4 , 1 , Coolinup Nature Reserve, South, Esperance, site ES 12, 33°43′53″S, 122°17′59″E, trap closed 2 May 2000 and 29 November 2000, pitfall trap, P. Van Heurck (WAM T71879); 4 , 3 , 5 juveniles, Coolinup Nature Reserve, SW, Esperance, site ES 13, 33°44′09″S, 122°17′29″E, trap closed 2 May 2000 and 29 November 2000, pitfall trap, P. Van Heurck (WAM T71880); 9 , 3 , 1 juvenile, Shark Lake Rd, Helms Arboretum Reserve, site ES 1, 33°44′49″S, 121°48′55″E, 15 October 1999–1 November 2000, pitfall, P. Van Heurck et al. (WAM T71881); 1 , Coolinup Nature Reserve, North, site ES 10, 33°34′02″S, 122°17′55″E, 15 October 1999–1 November 2000, pitfall, P. Van Heurck et al. (WAM T71882); 93 , 13 , 29 juveniles, Lake Morgan, Helms Arboretum Reserve, site ES 3, 33°43′09″S, 121°48′29″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T71883); remains only, Duke of Orleans Bay, Mt Belches near summit, site 1, 33°56′26″S, 122°34′31″E, 2 June 2007, hand collected under granite rocks M.L. Moir and A. Longbottom (WAM T80704); 1 , Cape Arid National Park, Seal Creek, 33°54′22″S, 123°30′35″E, 9 April 2007, *Banksia speciosa* woodland, G. Byrne (WAM T85346); 1 , Cape Arid National Park, Thomas River, 33°51′11″S, 123°01′00″E, 8 June 2012, K.E.C. Brennan et al. (WAM T124575).

DIAGNOSIS

Gonopod: *Antichiropus baudini* may be distinguished by the shape of the main femoral process: it is noticeably long and slender and follows the curve of the solenomere. In addition, there is a process near the base of the solenomere that is short, rounded and almost leaf-like in appearance (Figures 9D–G).

DESCRIPTION

Male holotype

Body c. 24 mm long; midbody ring c. 1.75 mm wide, with distinct beaded waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 9A); legs slightly paler than body. Paranota small but distinct (Figure 9C). l. Sternites without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks at least partially obscuring cardines, when viewed face-on, maximum width face c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 0.6 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) thicker and shorter than femorite, with slight ridge on anterior surface (not obvious in Figure 9); prefemur (PF) somewhat shorter than femorite, a noticeable prefemoral lip; femorite (F) c. 2/3 of acropodite length in situ, slightly curved when viewed anteriorly, upright, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, banana-shaped and following solenomere curve; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) long enough to form more than one loop or circle, generally more slender than femorite, and of similar thickness along length; solenomere tip pointed, with serrations (Figure 9B); solenomere process (spl) closer to solenomere tip than base, prominent, pointed, upright, slender; second solenomere process (sp2) near solenomere base, small and leaf-shaped (Figures 9D–G).

Female

Similar to male but slightly broader (c. 2 mm) when viewed dorsally (WAM T80694).

DISTRIBUTION

Many specimens of this species were collected from Esperance (33°52′S, 121°53′E) in the west to Cape Arid National Park (33°58′S, 123°10′E) the most easterly point, just south of the Great Western Woodlands (Figure 35).

ETYMOLOGY

The species name is in honour of Nicolas Baudin (1754–1803), who led an expedition from France to Australia and was the first European explorer to chart the Western Australian coastline.

***Antichiropus buchanorum* sp. nov.**

Figures 4C, 10, 36

http://www.zoobank.org/urn:lsid:zoobank.org:act:6F28338B-A623-4FF1-A113-511575057359

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Dundas Rocks, Coolgardie-Esperance Highway, 32°23′27.4″S, 121°46′22.3″E, 22 September 2011, damp litter at base of dam walls, J.M. Waldock and C.A. Car (WAM T121012).

Paratypes

Australia: ***Western Australia*:** 5 , 6 , collected with holotype (WAM T115034).

FIGURE 10 *Antichiropus buchanorum* sp. nov.: paratype male (WAM T115034) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

Other material

Australia: ***Western Australia*****:** 1 , 1 , details as for type specimens, but collected dead under granite rock on outcrop, J.M. Waldock and C.A. Car (WAM T115035).

DIAGNOSIS

General: this is the smallest species found in the Great Western Woodlands, with two distinctive pale dorsal stripes (Figures 10A, B). Gonopod: *Antichiropus buchanorum* may be distinguished further by the shape of the solenomere which is very stout and rounded midway along its length, and has the appearance of being folded over the basal third, and by the shape of two processes on the solenomere: the first is noticeably long, reaching almost to the solenomere tip while the second arises from the thick central section of the solenomere and is distinctly forked at its tip (Figures 10C–F).

DESCRIPTION

Male holotype

Body c. 15 mm long; midbody ring c. 1.0 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 10A), with

two pale dorsal stripes, running full length of body: legs noticeably paler than general body colour. No paranota on posterior rings (Figure 10B). Sternites without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.5 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and shorter than femorite, with slight ridge on anterior surface (damaged in Figures 10C–F); prefemur (PF) somewhat shorter than femorite, appearing to hug femorite base, noticeable prefemoral lip; femorite (F) contributing to c. 2/3 of acropodite length in situ, slightly curved when viewed anteriorly, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed, finger-like; second femoral process (fp1) present, arising close to solenomere base, rounded, short, triangular; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, thicker than femorite at least in part, and much thicker midway along length; solenomere tip with single flattened end and no serrations; solenomere process (sp1) near solenomere tip, prominent, pointed, upright, slender; second solenomere process (sp2) positioned halfway along solenomere, prominent, pointed with 2 branches (Figures 10C–F).

Female

Similar to male, but slightly larger and noticeably broader (c. 2 mm) (WAM T115034).

DISTRIBUTION

This species is known only from the granite outcrops known as Dundas Rocks, c. 25 km south of Norseman (Figure 36).

ETYMOLOGY

The species epithet is a patronym in honour of the senior author's parents, Terry and Kathy Buchan, who fostered her life long interest in terrestrial invertebrates.

Antichiropus cavernus sp. nov.

Figures 3B, 11, 35

http://www.zoobank.org/urn:lsid:zoobank.org:act:6C039B59-BDD5-4AAD-9BF1-EA31CF97D917

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , N of Madura, Mullamullang Cave (6N–37), doline, 31°43′S, 127°13′E, 4 September 1985, B. Knott (WAM T78708).

Paratypes

Australia: ***Western Australia*:** 2 , collected with holotype (WAM T72020).

Other material

Australia: ***Western Australia*:** 1 , Fern Cave doline, 6N-747, Nullarbor region, 31°50′S, 126°40′E, 2 October 1994, R. Foulds (WAM T42305); 1 , Mullamullang Cave (6N–37), doline, 31°43′S, 127°13′E, 4 September 1985, B. Knott (WAM T112939).

DIAGNOSIS

General: *Antichiropus cavernus* is similar in many aspects to *A. mammillifer*. Both have small distinctive protuberances on the sternites of the fifth body ring, posterior to the sternal lamella (Figure 11B), presumably the feature after which *A. mammillifer* was named. *A. cavernus*, however, has been found only on the eastern edge of Western Australia and *A. mammillifer* only on the Eyre Peninsula of South Australia. *A. cavernus* is also considerably smaller than *A. mammillifer* (Figure 11A). Gonopod: each species has a large spoon-shaped tip to the solenomere, a slender, pointed, serrated main femoral process that curves tightly towards the solenomere and a large, bulbous, pointed second femoral process (see Remarks). *A. cavernus* lacks the protuberance on the femur as shown by *A. mammillifer* in posterior view and has a shorter, relatively slender main femoral process. In addition, both the main femoral process and the second femoral process in *A. cavernus* are held horizontally in relation to the vertical femur whereas in *A. mammillifer*, they are both held at a 45° angle. *A. cavernus* is similar also to *A. rex* (Figures 28D–G) and *A. simpulus* (Figures 32D–G) but is distinguishable by its bulbous second femoral process (Figures 11D–G).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Legs relatively longer than in other species from the region, c. length of 2 midbody rings. Colour dark brown overall (Figure 11A); leg colour as for body. Paranota on posterior body rings present as slight protuberances (Figure 11C). Sternites, except ring 5, with protuberances on some, sternite of ring 5 with processes pointing anteriorly (Figure 11B), sternal lamella narrow, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker than and slightly shorter than femorite, with noticeable ridge

on anterior surface; prefemur (PF) somewhat shorter than femorite, appearing to hug femorite base, a small prefemoral lip; femorite (F) contributing to c. 1/2 of acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed, serrated on one edge, spear-shaped; second femoral process (fp1) curved, pointed, stout, bulbous; prolongation of femur (prof) absent; solenomere (S) very long extending in situ to 1/2 acropodite length, thicker than femorite at least in part, thickest nearer tip; solenomere tip flattened, with no serrations, distinctive spoon-shaped apex (Figures 11D–G); solenomere process (sp1) near solenomere tip, tiny ridge-like, not seen in Figure 11, but very similar to that of *A. simpulus* (Figure 32B).

Female

No female specimens have been collected.

REMARKS

With regards to the species from the Great Western Woodlands that possess large 'spoon-shaped' tips to their solenomeres, there is some difficulty in assigning the various femoral processes to the categories established in Car et al. (2013). As before, the main femoral process is recognised as that process which arises on the lateral surface of the femorite. Each of three species, *A. cavernus*, *A. rex* and *A. simpulus* carries a second femoral process, labelled here fp1. For consistency, what was labelled as a prolongation of the femur in *A. mammillifer* (Car et al. 2013) is here relabelled the fp1 for easier comparison.

DISTRIBUTION

This species has been found only on the extreme eastern edge of the Great Western Woodlands, and is the most

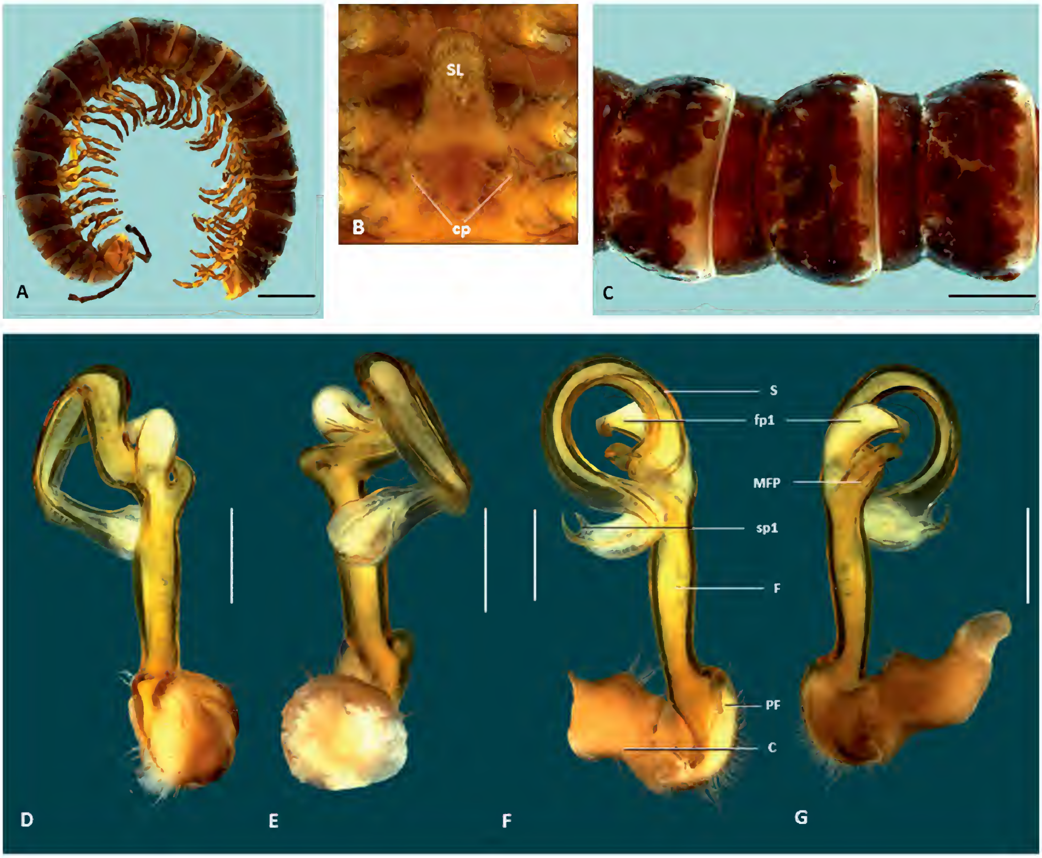

FIGURE 11 *Antichiropus cavernus* sp. nov.: A and C male (WAM T112939) habitus: A, lateral view; C, dorsal view; B, male (WAM T112939) sternal view of fifth body ring; D–G, paratype male (WAM T72020) left gonopod: D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; cp, coxal processes; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; SL, sternal lamella; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 0.2 mm; C = 1 mm; D–G = 0.5 mm.

easterly species found in Western Australia (Figure 35).

ETYMOLOGY

This species is named for the fact that it has been found only in caves (Latin, noun, *caverna*, cave).

Antichiropus cincinnus **sp. nov.**

Figures 4A, 12, 36

http://www.zoobank.org/urn:lsid:zoobank.org:act:6F4A20C7-7B24-4E94-8D53-16B23E482AA4

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*****:** , McDermid Rock, site MRR 4, 32°01′40″S, 120°44′45″E, *Eucalyptus salmonophloia* woodland, 1981, W.F. Humphreys (WAM T72055).

Other material

None

DIAGNOSIS

Gonopod: *Antichiropus cincinnus* is recognised by the extremely short, bent femorite and by what appears to be a fusion of two femoral processes to form a large distinctive two-headed main femoral process (Figures 12C–F).

DESCRIPTION

Male holotype

Body damaged, length not determined; midbody ring c. 2 mm; with distinct waist, metazonite distinctly wider than prozonite. Colour bleached in alcohol (Figure 12A, B). No paranota on posterior rings (Figure 12B). Pore formula difficult to determine. Sternites, except ring 5, with protuberances on some, long setae

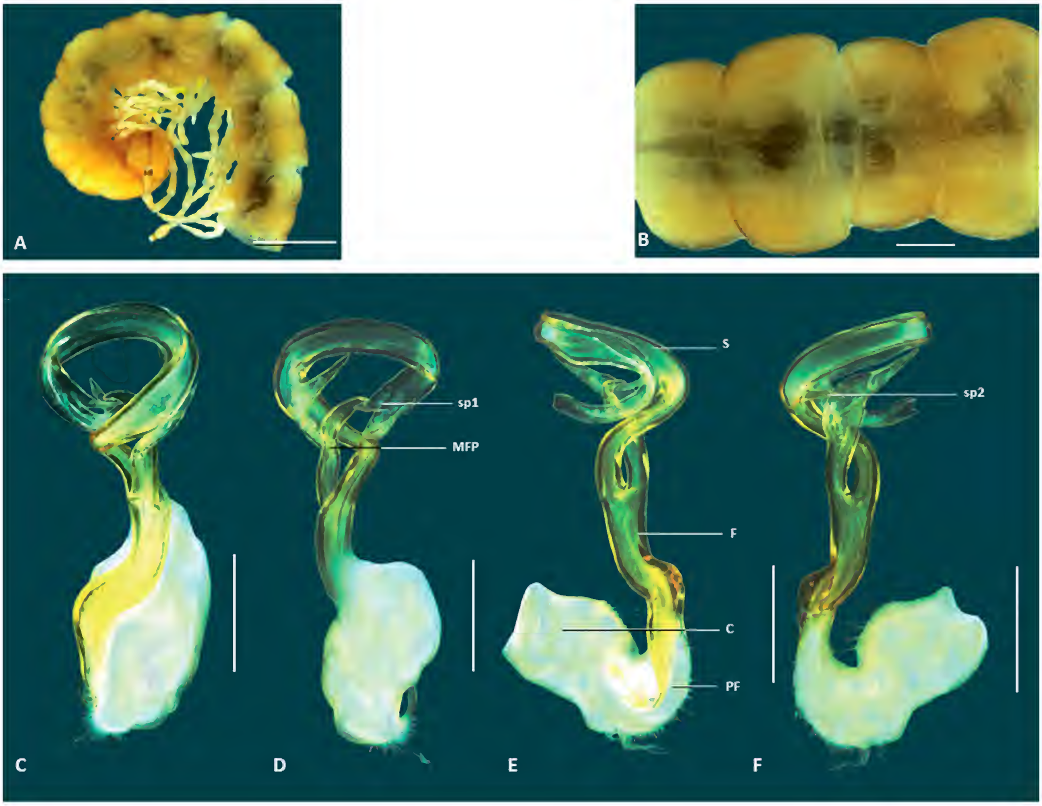

FIGURE 12 *Antichiropus cincinnus* sp. nov.: holotype male (WAM T72055) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1 and sp2 solenomere processes 1 and 2. Scale bars: A = 2 mm; B–F = 0.5 mm.

on protuberances, sternites of ring 5 without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 4 x the distance between antennal sockets; sockets separated by c. 1.5 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod short, reaching to ring 6; coxa (C) more robust, thicker and longer than femorite, with no noticeable ridge; prefemur (PF) longer than femorite (Figure 4); femorite (F) less than 1/2 acropodite length in situ, bent when viewed medially, becoming thicker towards apex; main femoral process (MFP) very long, to 1/2 solenomere length, pointed, but not spine-like, irregularly shaped, comprising 2 pointed processes; prolongation of femorite apex (prof) absent; solenomere (S) held in different plane from femorite, i.e. in Figure 12E, femorite is shown as vertical and solenomere appears orientated horizontally, relatively short, forming circle, generally same thickness as femorite, of similar thickness along length but thinner at tip; solenomere tip flattened, with no serrations, indeterminate; solenomere process (spl) prominent, pointed, triangular; second solenomere process (sp2) positioned c. halfway along solenomere, prominent, pointed (Figures 12C–F).

Female

No female known.

DISTRIBUTION

Only one specimen has ever been collected and that from woodlands at the base of McDermid Rock in the Great Western Woodlands (Figure 36). Interestingly, another species, *A. paracalothamnus* was collected on the granite surface of McDermid Rock.

REMARKS

The only specimen used for montage images and scanning electron microscopy.

ETYMOLOGY

The species name refers to the shape of the male gonopod (Latin, noun, *cincinnus,* lock of hair).

***Antichiropus cuspis* sp. nov.**

Figures 13, 36

http://www.zoobank.org/urn:lsid:zoobank.org:act:117B9177-7B39-4C19-9A53-54C5EAB8BAF5

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*****:** , Ravensthorpe Range South (site WAM 22), 33°38′31.00″S, 120°13′50.00″E, 96 m, 16 September 2007, hand collected under rock, M.C. Leng and J. Newell (WAM T81288).

Paratypes

Australia: ***Western Australia*****:** 5 , 3 , 8 juveniles, Ravensthorpe Range South (site WAM 22), 33°38′31.06″S, 120°13′50.00″E, 130 m, 19 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80844).

Other material

Australia: ***Western Australia*****:** 1 , 34.2 km E of Ravensthorpe, 33°39′47″S, 120°24′01″E, 24 August 2005, R. Teale and Z. Hamilton (WAM T66416); 3 , 2 juveniles, 24.4 km E of Ravensthorpe, 33°34′22″S, 120°18′28″E, 26–27 August 2005, R. Teale and Z. Hamilton (WAM T66417); 1 , 24.4 km E. of Ravensthorpe, site RNOCTS2, 33°34′22″S, 120°18′28″E, 26–27 August 2005, dry pitfall, R. Teale and Z. Hamilton (WAM T78187); 3 , 4 , 3 juveniles, Bremer Bay, Peppermint Beach, southern end, 34°23′37″S, 119°29′32″E, 7 June 2007, hand collected under granite rocks, M.C. Leng and M.L. Moir (WAM T80655); 1 , Bremer Bay, Peppermint Beach, southern end, 34°23′37″S, 119°29′32″E, 7 June 2007, hand collected under granite rocks, M.C. Leng and M.L. Moir (WAM T80656); 1 , 1 juvenile, Fitzgerald River National Park, Eyre Range, rock outcrop, unburnt, site 3, 33°51′11″S, 119°57′58″E, 30 May 2007 hand collected under rock, M.C. Leng and M.L. Moir (WAM T80792); 1 , Fitzgerald River National Park, Eyre Range, gully, unburnt, site 1, 33°50′50″S, 119°57′07″E, 30 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80810); 1 , Fitzgerald River National Park, Eyre Range, rock outcrop, unburnt, site 2, 33°51′01″S, 119°57′32″E, 30 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80811); 1 , Ravensthorpe Range South (site WAM 22), 33°38′31.06″S, 120°13′50.00″E, 130 m, 19 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80845); 1 , Ravensthorpe Range South (site WAM 14), 33°41′53.07″S, 120°18′00.02″E, 115 m, 18 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80890); 2 , 3 juveniles, Ravensthorpe Range South (site WAM 17), 33°40′35.02″S, 120°17′59.08″E, 81 m, 18 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80900); 1 , 5 juveniles, Ravensthorpe Range North (site WAM 27), 33°27′38.09″S, 120°00′00.00″E, 358 m, 20 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80932); 1 , 2 , 6 juveniles, Ravensthorpe Range North (Site WAM 30), 33°32′58.03″S, 120°06′12.01″E, 226 m, 21 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80949); 1 , Ravensthorpe Range North (site WAM 34), 33°33′06.01″S, 120°08′48.06″E, 150 m, 22 May 2007 hand collected under rock,

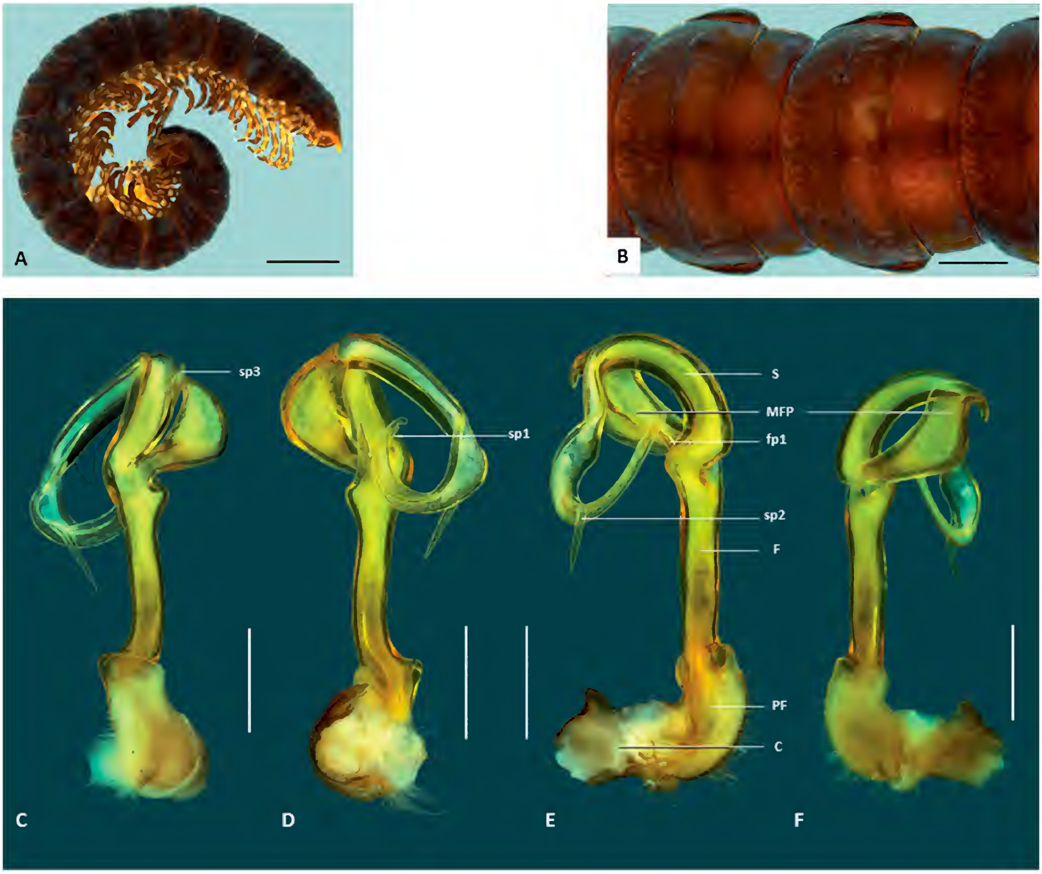

FIGURE 13 *Antichiropus cuspis* sp. nov.: A-B, male (WAM T80810) habitus: A, lateral view; B, dorsal view; C–F, holotype male (WAM T81288) left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1, sp2 and sp3, solenomere processes 1, 2 and 3. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

M.C. Leng and M.L. Moir (WAM T80968); 4 , 4 juveniles, Ravensthorpe Range North (site WAM 36), 33°31′13.09″S, 120°03′34.01″E, 379 m, 23 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80977); 1 juvenile, Ravensthorpe Range North, Mt McMahon area (site WAM 38), 33°33′18.05″S, 120°06′46.04″E, 266 m, 23 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T80983); 3 , 2 juveniles, Ravensthorpe Range Middle, near townsite (site WAM 48), 33°34′04.09″S, 120°02′51.05″E, 210 m, 28 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T81020); 1 , 1 juvenile, Ravensthorpe Range Middle (Site WAM 49), 33°34′59.08″S, 120°07′36.07″E, 201 m, 28 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T81029); 2 , 8 juveniles, Ravensthorpe Range, Bandalup Hill (site WAM 51), 33°40′16.01″S, 120°24′35.05″E, 153 m, 29 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T81034); 2 , Ravensthorpe Range, Bandalup Hill (site WAM 52), 33°40′34.01″S, 120°23′59.04″E, 163 m, 29 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T81039); 6 , 1 , 1 juvenile, Ravensthorpe Range, Bandalup Hill (site WAM 54), 33°39′40.06″S, 120°23′02.09″E, 148 m, 29 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T81045); 1 , Calyerup Rocks, 33°54′40.1″S, 119°06′02.5″E, 23 October 2008, dead on sand track near rocks, J.M. Waldock, S. Crews, F. Stone and D. Ward (WAM T94019); 1 , Ravensthorpe Range, Bandalup Hill (site

WAM 54), 33°39′40.06″S, 120°23′02.09″E, 148 m, 29 May 2007, hand collected under rock, M.C. Leng and M.L. Moir (WAM T112943).

DIAGNOSIS

Gonopod: *Antichiropus cuspis* has a noticeably large, very broad, uniquely shaped femoral process and three solenomere processes, the most prominent of which is highly visible and positioned c. two-thirds of the way from the base of the long, looping solenomere towards its tip (Figures 13C–F).

DESCRIPTION

Holotype male

Body c. 20 mm long; midbody ring c. 1.75 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 13A); leg colour as for body. Paranota on posterior rings small, distinct (Figure 13B). Sternites, except ring 5, with no noticeable features, sternite of ring 5 with slight processes, pointing anteriorly, sternal lamella relatively narrow, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons setose; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.3 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres relatively robust. Collum 0.8 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and shorter than femorite; prefemur (PF) of similar length to femorite, ovoid, a noticeable prefemoral lip; femorite (F) c. 1/2 of acropodite length in situ, upright, with noticeable ‘elbow’ at femorite base when viewed anteriorly, of similar thickness along length; main femoral process (MFP) very long, broad, c. 1/2 of solenomere length, pointed, irregularly shaped; second femoral process (fp1) present, arising close to solenomere base, upright, pointed, short, triangular; prolongation of femorite apex (prof) absent; solenomere (S) very long, extending to prefemur, thicker than femorite in part, thickest midway along length; solenomere tip pointed, with no serrations; solenomere process (sp1) near solenomere tip, small, pointed, slender; second solenomere process (sp2) in apical 1/3 of solenomere, long, prominent, pointed; third solenomere process (sp3) near solenomere base, prominent, broadly pointed (Figures 13 C–F).

Female

Similar to male, but slightly broader (dorsal width c. 2.5 mm) (WAM T112943).

DISTRIBUTION

This species has been collected from a number of localities from under rocks in the granite outcrops of the Fitzgerald River National Park and the Ravensthorpe Range (Figure 36).

ETYMOLOGY

The species name refers to the several pointed processes on the solenomere of the male gonopod (Latin, noun, *cuspis,* the pointed end of anything).

***Antichiropus digitatus* sp. nov.**

Figures 14, 36

http://www.zoobank.org/urn:lsid:zoobank.org:act:66141F0E-5527-4560-98C1-C475AE65AE18

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Dongolocking Spring Reserve, site DU 02, 33°05′19″S, 117°41′29″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T132357).

Paratypes

Australia: ***Western Australia*:** 10 , 8 , collected with holotype (WAM T71992, T71993).

Other material

None.

DIAGNOSIS

Gonopod: the most striking diagnostic feature of *Antichiropus digitatus* is the large process on the solenomere which is almost long enough to reach the tip of the solenomere. This process and the tip together give the impression of a finger and thumb when viewed medially (Figure 14E). The gonopod is relatively simple with few processes.

DESCRIPTION

Male holotype

Body c. 27 mm long; midbody ring c. 2.5 mm wide, with distinct beaded waist, prozonite and metazonite of similar width. Colour chestnut brown overall with broad, pale, dorsal stripe running full length of body (Figure 14A); leg colour as for body. No paranota on posterior rings (Figure 14B). Sternites without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width 2.9 x the distance between antennal sockets; sockets separated by c. 2.5 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching to posterior edge of ring 5; coxa (C)

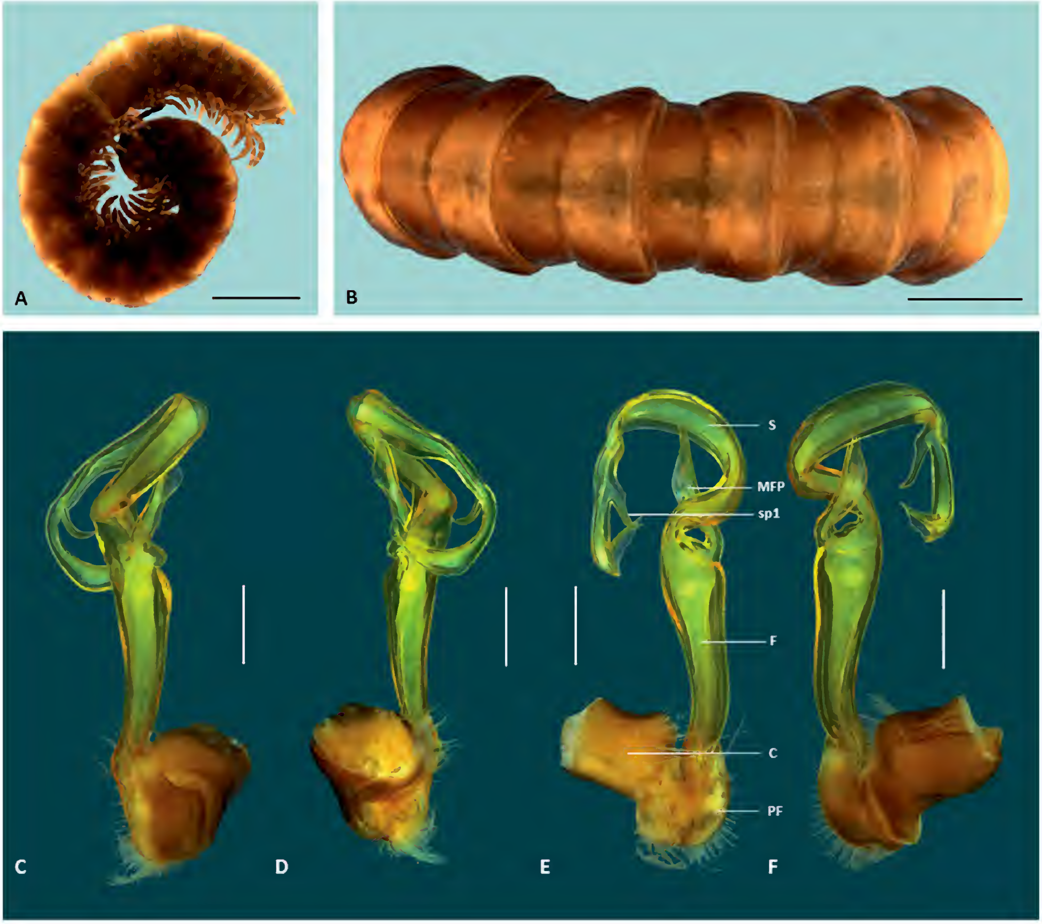

FIGURE 14 *Antichiropus digitatus* sp. nov.: A–B, holotype male (WAM T71993) habitus: A, lateral view; B, dorsal view; C–F, paratype male (WAM T71992) right gonopod image flipped: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

more robust, thicker, of similar length to femorite, with noticeable ridge on anterior surface; prefemur (PF) somewhat shorter than femorite; femorite (F) contributing to c. 1/2 acropodite length in situ, upright, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, spear or flame-shaped; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) long enough to form more than 1 loop or circle, generally more slender than femorite, thickest midway along length, narrowing abruptly in apical 1/3; solenomere tip broadly pointed, with no serrations, single flattened end; solenomere process (sp1) in apical 1/3 of solenomere, prominent, pointed, upright, thumb-like and slender (Figures 14 C–F).

Female (WAM T71993) similar in colour and length to male, but slightly broader (c. 3 mm).

DISTRIBUTION

This species is only known from specimens collected at Dongolocking Spring Reserve (Figure 36).

ETYMOLOGY

This species is named for the distinctive shape of the solenomere tip (Latin, *digitatus*, having fingers).

Antichiropus equinus sp. nov.

Figures 15, 38

http://www.zoobank.org/urn:lsid:zoobank.org:act:21994AFE-007B-4027-816B-EC5779CFF1F1

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*****:** , Lake King-Norseman Road, site LK13, 33°04’54″S, 119°59’53″E, 15 October 1999–25 October 2000, wet pitfall, N. Guthrie (WAM T124608).

Paratypes

Australia: ***Western Australia*****:** 43 , 26 , 8 juveniles, collected with holotype (WAM T72616, T72617, T72618, T112942).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus equinus* is distinguishable from other similar species, namely *A. anconus*, by a combination of gonopodal features. The main femoral process is of a distinctive shape: large and very stout,

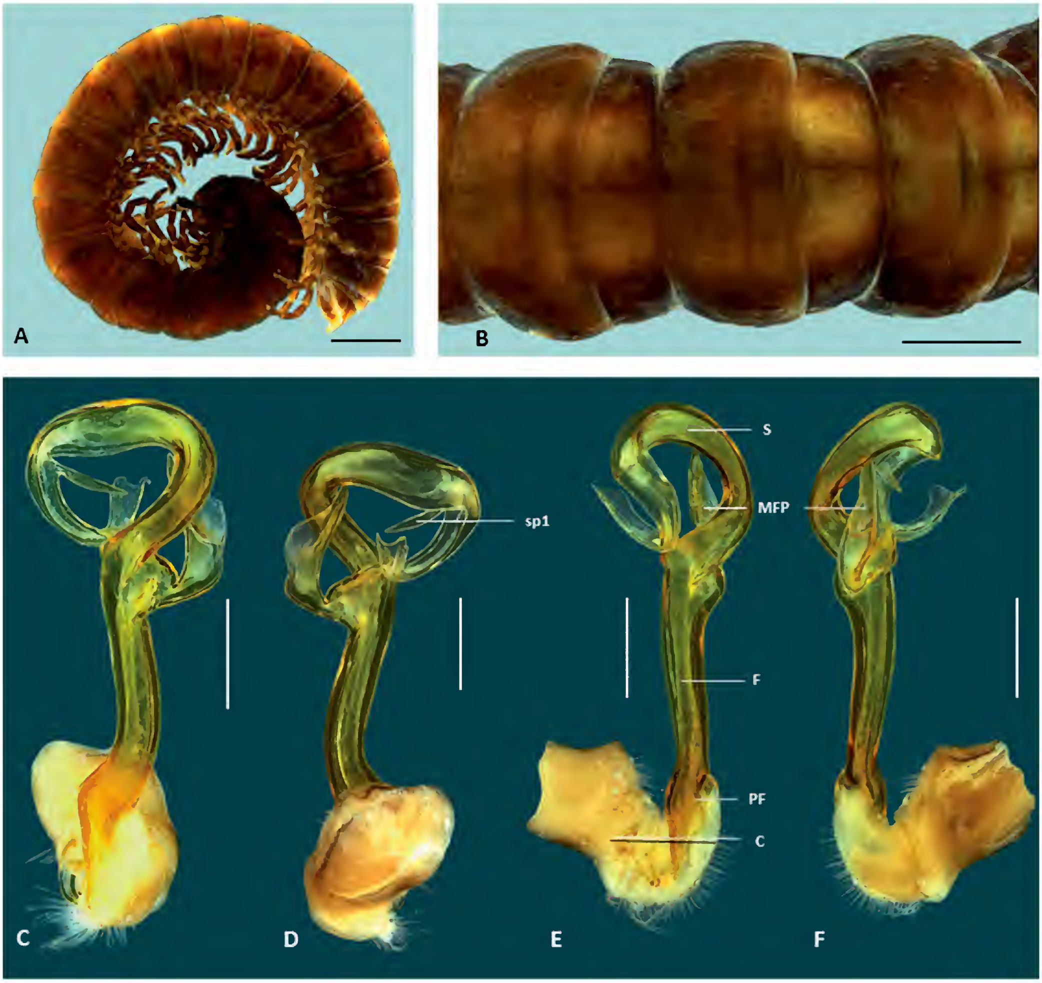

FIGURE 15 *Antichiropus equinus* sp. nov.: paratype male (WAM T72616) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

with a transparent flange running along its pointed tip. The second femoral process is broad, short and triangular and more prominent than that of *A. anconus* (Figures 7D, 15D). The solenomere ends in a spatulate, slightly bilobed tip which, under high magnification, reveals serrations. There is a single, prominent, pointed process that arises c. two-thirds along the length of the solenomere from its base: *A. anconus* has three distinct solenomere processes.

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 15A); leg colour as for body. No paranota on posterior rings (Figure 15C). Sternites without obvious processes/ tubercles, sternal lamella broad, heart-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.7 x the distance between antennal sockets; sockets separated by c. 1.5 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and of similar length to femorite, with noticeable ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid, appearing to hug femorite base, small prefemoral lip; femorite (F) contributing to c. 1/2 of acropodite length in situ, upright, slightly curved when viewed anteriorly, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), relatively stout with pointed tip, transparent flange at tip, irregularly shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, short, broadly triangular; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, generally thicker than femorite, thickest midway along length; solenomere tip flattened, with serrations and several lobes; solenomere process (sp1) positioned c. halfway along solenomere, prominent, pointed, upright, slender (Figures 15B, D–G).

Female

Similar to the male but slightly broader, width c. 3 mm (WAM T112942).

DISTRIBUTION

This species is known only from specimens collected from a wet pitfall trap set near the edge of the Lake King-Norseman Road (Figure 38).

ETYMOLOGY

The species name refers to a town in the area, Norseman, that was named after a horse (Latin, *equinus*, of horses).

***Antichiropus exclamatus* sp. nov.**

Figures 2, 16, 37

http://www.zoobank.org/urn:lsid:zoobank.org:act:F5006273-D1B6-4221-BFE4-48CC97CF1B39

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Exclamation Lake, site SG 06A, 32°46′22″S, 121°23′52″E, 23–29 April 2002, pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71927).

Paratypes

Australia: ***Western Australia:*** 1 , Exclamation Lake, site SG 05B, 32°49′18″S, 121°24′45″E, 29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71928); 4 , 5 , Exclamation Lake, site SG 01A, 32°48′26″S, 121°26′49″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71930).

Other material

Australia: ***Western Australia:*** 7 , 2 , 1 juvenile, Salmon Gums, 32°58′59″S, 121°38′42″E, 23 July 2007, in mallee litter under logs, C.A. Car (WAM T54242); 1 , Norseman, 32°09′47″S, 121°47′50″E, 23 July 2007, in mallee litter, C.A. Car (WAM T54243); 1 , N of Mt Dean (via Norseman), 32°17′23″S, 121°26′03″E, 12 May 2005, open saltbush, eucalypts on limestone soil under log, A.F. Longbottom (WAM T66523); 3 , Exclamation Lake, site SG 08B, 32°41′48″S, 121°26′31″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71917); 1 , Exclamation Lake, site SG 08A, 32°41′48″S, 121°26′31″E, 23–29 April 2002 dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71919); 2 , Exclamation Lake, site SG 09B, 32°42′26″S, 121°29′31″E, 23–29 April 2002, pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71920); 1 , Pyramid Lake, East, site GP 04, 33°09′31″S, 120°00′03″E, 15 October 1999–26 November 2000, wet pitfall, B. Durrant (WAM T71921); 3 , Pyramid Lake, East, site GP 04, 33°09′31″S, 120°00′03″E, 15 October 1999–26 November 2000, wet pitfall, B. Durrant (WAM T71922); 1 , 1 juvenile, Exclamation Lake, site SG 10B, 32°41′55″S, 121°29′11″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71925); 2 , Exclamation Lake, site SG 07B, 32°49′59″S, 121°24′50″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71926); 2 , Exclamation Lake, site SG 03B, 32°47′51″S, 121°24′09″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and

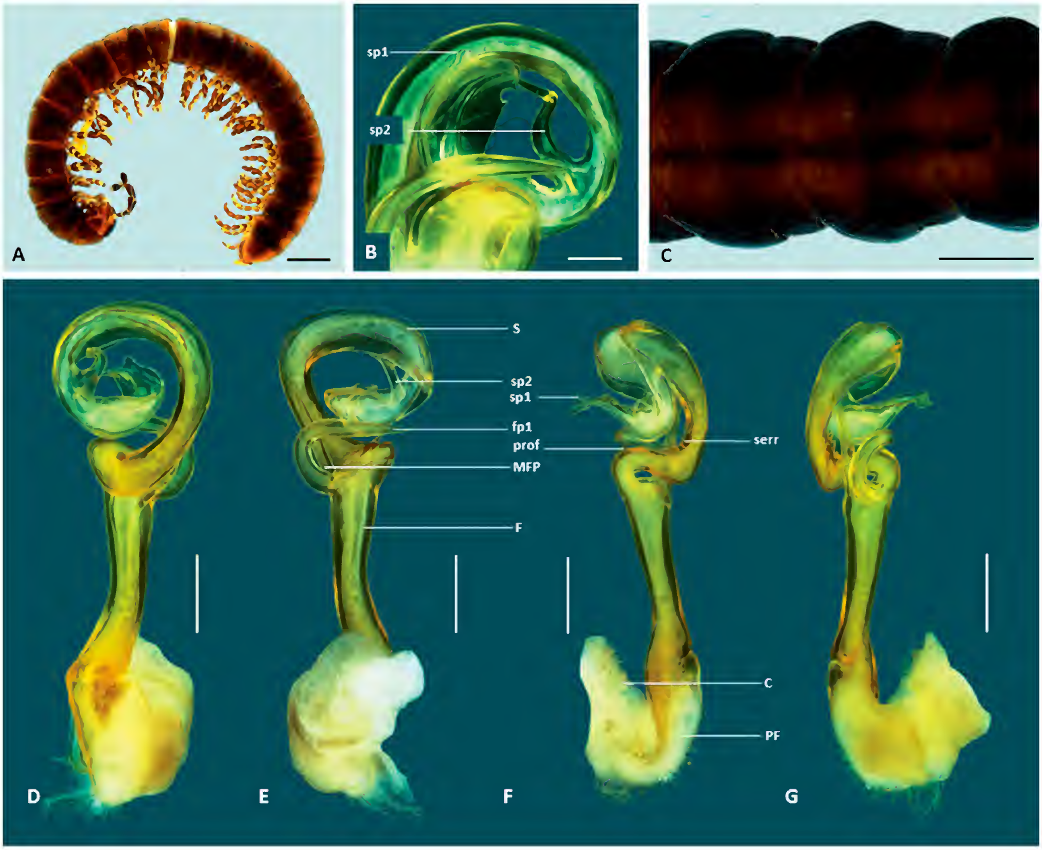

FIGURE 16 *Antichiropus exclamatus* sp. nov. A, C paratype male (WAM T71928) habitus: A, lateral view; C, dorsal view; B, D–G holotype male (WAM T71927) left gonopod: B, anterior view, detail of solenomere tip; D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; serr, serrations; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 0.2 mm; C = 1 mm; D–G = 0.5 mm.

P. Higgs (WAM T71929); 1 , 4 , Exclamation Lake, site SG 12, 32°51′43″S, 121°24′04″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T71940); 2 , 1 , Pine Hill, 33°18′S, 123°23′E, 24 May 1986, B. Y. Main (WAM T72536); 2 , 2 , c. 32 km NW of Salmon Gums, 32°46′35″S, 121°23′46″E, September 2008, opportunistic, K. George and M. Peterson (WAM T95225); 1 , c. 35 km NW of Salmon Gums, Rapallo site 4A, 32°43′02″S, 121°25′00″E, October–November 2008 pitfall trap, K. George and M. Peterson (WAM T95226); 2 , c. 28 km NW of Salmon Gums, Rapallo site 7A, 32°45′55″S, 121°25′36″E, October-November 2008, pitfall trap, K. George and M. Peterson (WAM T95229); 1 , c. 28 km NW of Salmon Gums, Rapallo site 7, 32°45′55″S, 121°25′36″E, October-November 2008, night forage, K. George and M. Peterson (WAM T95230); 1 , c. 28 km NW of Salmon Gums, Rapallo site 7B, 32°45′58″S, 121°25′36″E, October-November 2008 day forage, K. George and M. Peterson (WAM T95231); 1 , Exclamation Lake, site SG 05B, 32°49′18″S, 121°24′45″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T112932); 1 , Exclamation Lake, site SG 12, 32°51′43″S, 121°24′04″E, 23–29 April 2002, dry pitfall, R. Teale, G. Harold, A. Sanders and P. Higgs (WAM T112933); 2 , 2 , Newman Rocks, 32°06′50.9″S, 123°10′22.6″E, 3 August 2012 by hand, under rocks in gully below large pool, J.M. Waldock (WAM T126101).

DIAGNOSIS

Gonopod: *Antichiropus exclamatus* is recognisable by a combination of characters in a telopodite that is the

most complex looking of all those in the Great Western Woodland species: the solenomere is thickest midlength and carries a large L-shaped process, and the second femoral process is slender, pointed and curves into a C-shape (Figures 16D–G).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 16A); leg colour as for body. No paranota on posterior rings (Figure 16C). Sternites without obvious processes/tubercles, transverse sternal cross impressions not noticeably different from longitudinal, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.1 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) thicker, but similar length to femorite, with noticeable ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid; femorite (F) contributing to c. 1/2 of acropodite length in situ, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed, spear or flame-shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, slender along length; prolongation of femorite apex (prof) present as slight projection, orientated anteriorly; solenomere (S) long, forming >1 loop/circle, thicker than femorite in part, thickest nearer tip; solenomere tip flattened, with no serrations, ribbon like; solenomere process (sp1) at tip, small pointed; solenomere process (sp2) near solenomere tip, prominent, curved, L-shaped (Figures B, D–G).

Female

Similar to male in length, but slightly broader (slightly less than 3 mm wide) (WAM T71930).

DISTRIBUTION

This species is remarkable as one of those from the Great Western Woodlands that has a relatively broad distribution, stretching from Pyramid Lake (33°09′31″S, 120°00′03″E) to Newman Rocks (32°06′50.9″S, 123°10′22.6″E) (Figure 37).

ETYMOLOGY

This species was named for the type locality, Exclamation Lake, and is derived from the Latin word *clamatus* (Latin, cry out, shout, call).

Antichiropus framenaui **sp. nov.**

Figures 17, 37

http://www.zoobank.org/urn:lsid:zoobank.org:act:3E02AA85-C85C-405F-9209-2B2CA9F256C6

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Mt Jackson area, site MJ07, 30°13′30″S, 119°09′40″E, 18 August 2006, under leaf litter, W. Bancroft and B. Metcalf (WAM T98571).

Paratypes

Australia: ***Western Australia:*** 2 , 1 , 1 juvenile, Bungalbin Hill, 49 km NNE of Koolyanobbing, 30°23′32.03″S, 119°37′47.10″E, 3–11 April 2013, leaf litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130657); 2 , 1 juvenile, Bungalbin Hill, 53 km N of Koolyanobbing, 30°21′42.27″S, 119°37′06.48″E, 3–11 April 2013, leaf litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130663).

Other material

Australia: ***Western Australia:*** 1 , 13.2 km SE of Koolyanobbing, 30°53′06.97″S, 119°37′59.66″E, 20 August 2009, leaf litter, R. Teale (WAM T99029); 1 , 13.2 km SE of Koolyanobbing, 30°53′06.97″S, 119°37′59.66″E, 20 August 2009, leaf litter, R. Teale (WAM T99037); 1 , 10.0 km SE of Koolyanobbing, 30°52′16.66″S, 119°36′16.70″E, 22 August 2009, leaf litter, R. Teale (WAM T99084); 1 , Deception, 108.8 km N of Koolyanobbing, 29°51′30″S, 119°16′12″E, 30 June 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104622); 1 , Windarling, 92.5 km N of Koolyanobbing, 30°00′44″S, 119°15′32″E, 7 July 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104661); 1 , Windarling, 93.3 km N of Koolyanobbing, 30°00′26″S, 119°14′49″E, 4 July 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104673); 1 , 1 juvenile, c. 39 km W of Wallaroo, 30°23′54.31″S, 119°56′45.51″E, 17–24 May 2013, leaf litter, dense bushland, K. Bankin (WAM T128589); 1 , 1 juvenile, c. 39 km W of Wallaroo, 30°22′41.78″S, 119°55′17.47″E, 17–24 May 2013, leaf litter, open woodland, K. Bankin (WAM T128590); 1 , 1 juvenile, Bungalbin Hill, 53 km NNE of Koolyanobbing, 30°22′42.62″S, 119°41′56.69″E, 3–11 April 2013, leaf litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130647); 3 , 1 juvenile, Bungalbin Hill, 53 km N of, 30°21′43.17″S, 119°37′12.31″E, 3–11 April 2013, leaf litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130649); 1 , 1 , 3 juveniles, Bungalbin Hill, 53 km N of Koolyanobbing, 30°21′44.77″S, 119°37′17.51″E, 3–11 April 2013, leaf

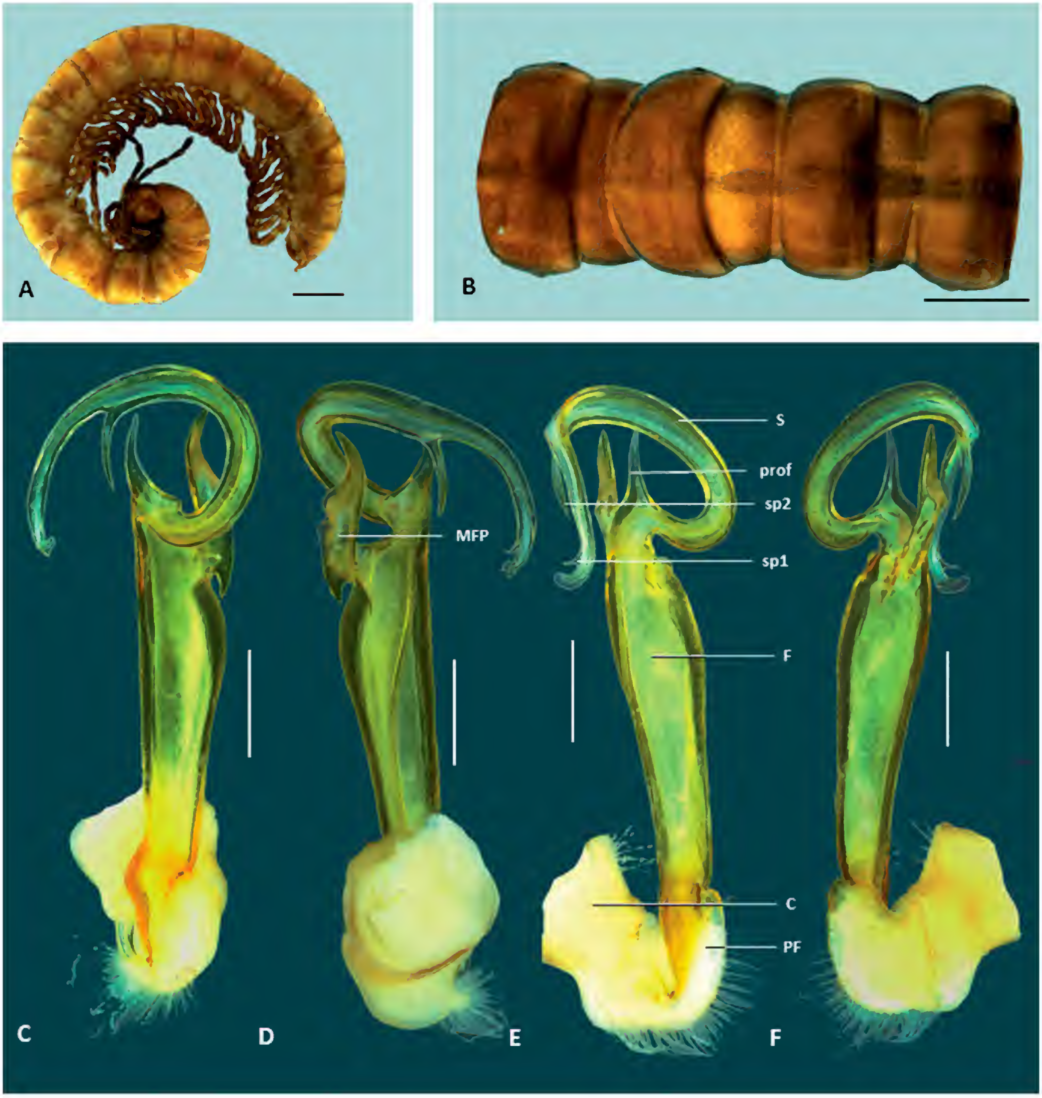

FIGURE 17 *Antichiropus framenaui* sp. nov.: A-B paratype male (WAM T130663) habitus: A, lateral view; B, dorsal view; C–F, holotype male (WAM T98571) left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130659).

DIAGNOSIS

Gonopod: *Antichiropus framenaui* can be characterised by a combination of features: a long, upright, robust femorite, an elongate slender solenomere which carries a short process at its tip and a long pointed second process in the apical third, as well as a well developed large pointed prolongation of the femorite. It may be distinguished from similar species such as *A. alastairi* (Figures 5C–F) by the unusual shape of the main femoral process which is pointed both anteriorly and posteriorly (Figure 17D). A. *giganteus*

(Figure 18D) has a similarly pointed main femoral process but of a noticeably different shape and this species lacks the femoral prolongation present in *A. framenaui*.

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour chestnut brown overall (Figure 17A); leg colour as for body. No paranota on posterior rings (Figure 17B). Sternites without obvious processes/tubercles, sternal lamella broad, helmet-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.6 x the distance between antennal sockets, sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively slender. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) thicker, shorter than femorite, with slight ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid, slight prefemoral lip; femorite (F) contributing to c. 2/3 of acropodite length in situ, upright, robust, thickest midway along length, becoming slightly thinner towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, irregularly shaped, pointed at both ends; second femoral process (fp1) absent; prolongation of femorite apex (prof) present, long, sharply pointed; solenomere (S) long, forming >1 loop/circle, much more slender than femorite, generally slender, tapering towards tip; solenomere tip with single flattened end and no serrations; solenomere process (sp1) near solenomere tip, small, pointed; second solenomere process (sp2) in apical 1/3 of solenomere, prominent, pointed (Figures 17C–F).

Female

Of similar length and colour to male but broader (at least 3 mm wide) (WAM T130657).

DISTRIBUTION

This species has been collected from the Mt Jackson area, Windjarling, near Koolyanobbing, and Deception (Figure 37).

ETYMOLOGY

The specific epithet is a patronym in honour of Volker Framenau in appreciation of his research on terrestrial invertebrates.

Antichiropus giganteus **sp. nov.**

Figures 18, 37

http://www.zoobank.org/urn:lsid:zoobank.org:act:A9AEE3D0-CB66-4E4A-A11E-BF70E55170C4

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Jouerdine Nature Reserve, site BE 3, 30°38′11″S, 118°25′39″E, wet pitfall trap, 15 September 1998–25 October 1999, L. King (WAM T72232).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus giganteus* is distinguishable by its relatively large, robust gonopod with a long, thick femorite and a broad flattened tip to the solenomere (Figures 18C–F). The femorite carries only one process which, like that of *A. framenaui*, is pointed both anteriorly and posteriorly, but in this species is very long and slender. *A. giganteus* can be separated from the superficially similar *A. sagittulus* (Figure 29C–F) by its solenomere lacking obvious processes.

DESCRIPTION

Male holotype

Body length c. 35 mm; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour bleached in alcohol (Figure 18A). No paranota on posterior rings (Figure 18B). Sternites without obvious processes/tubercles, sternal lamella broad, helmet-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.6 x the distance between antennal sockets; sockets separated by c. 2.5 x width of socket. Antennae of moderate length, reaching to ring 2 collum, distinctly clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod long, reaching well into ring 5; coxa (C) robust, thicker and shorter than femorite, with slight ridge (not seen in Figure 18); prefemur (PF) considerably shorter than femorite, ovoid, a noticeable prefemoral lip; femorite (F) contributing to c. 2/3 of acropodite length in situ, upright, becoming thicker towards apex; main femoral process (MFP) long (to 1/4 solenomere length), narrow, pointed, irregularly shaped; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, much more slender than femorite, thick at base, becoming thinner midlength, thickening again at tip; solenomere tip with single flattened end and no

serrations; solenomere process (sp1) near solenomere tip, tiny, pointed, slender (Figures 18C–F).

Female

No female specimens have been collected.

DISTRIBUTION

This species is known from a single male collected in a wet pitfall trap in Jouerdine Nature Reserve (Figure 37).

ETYMOLOGY

This species was named for the relatively large size of the male gonopods (Latin, adjective, *giganteus*, very large, gigantic).

FIGURE 18 *Antichiropus giganteus* sp. nov.: holotype male (WAM T72232) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 5 mm; B–F = 1 mm.

Antichiropus howardi sp. nov.

Figures 19, 37

http://www.zoobank.org/urn:lsid:zoobank.org:act:B791EA60-2B44-48B8-8DF5-2A54398F921C

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Marvel Loch, St Barbara Operation, 31°10′10.56″S, 119°18′16.05″E, 3 August 2008, under rock, P. Cullen and P. Langlands (WAM T132358).

Paratypes

Australia: ***Western Australia:*** 2 , 3 juveniles, collected with holotype (WAM T96079).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus howardi* is most similar to *A. incomptus* (Figures 20C–F), both possessing a very simple gonopod, but the species may be separated by several gonopodal features: *A. howardi* has a more robust femorite, a longer solenomere that tends to dip down towards the coxa in lateral view, and a larger solenomere process (Figures 19C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2 mm wide, with distinct waist, prozonite and metazonite of similar

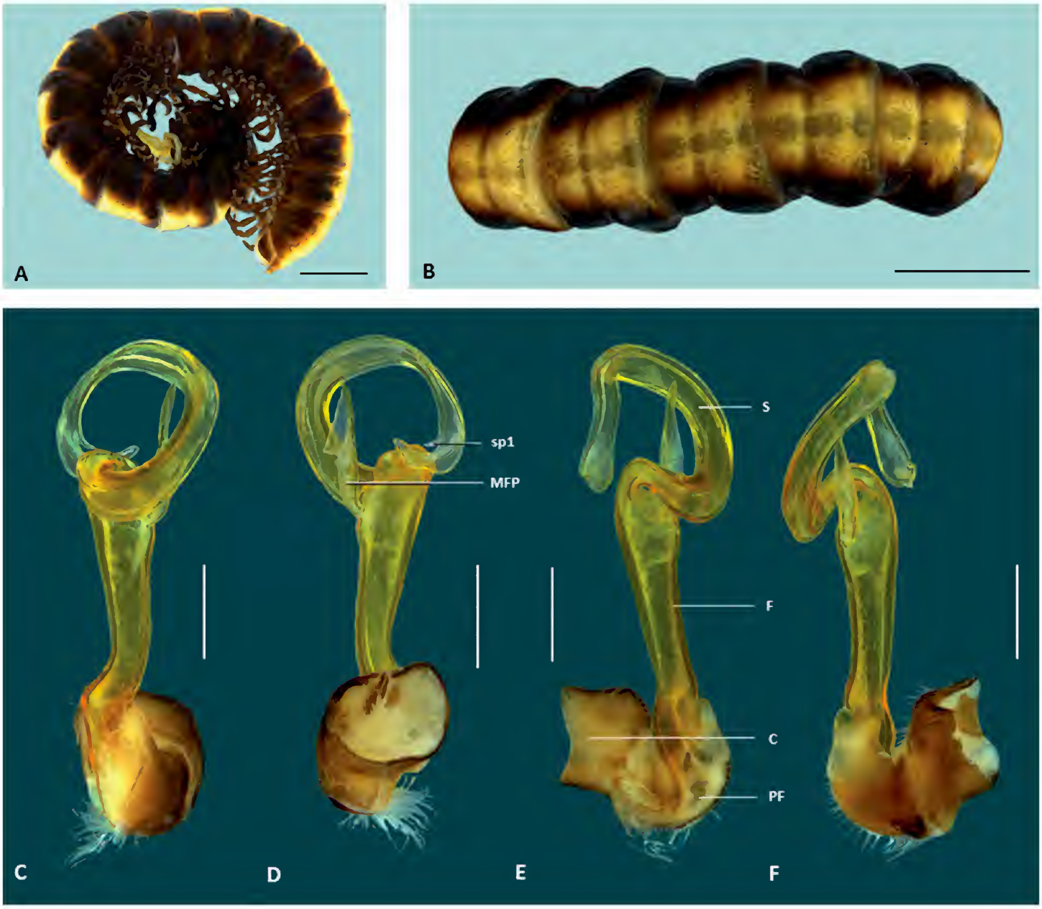

FIGURE 19 *Antichiropus howardi* sp. nov.: paratype male (WAM T96079) habitus: A, lateral view; B, dorsal view; C–F left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 2 mm; C–F = 0.5 mm.

width. Colour dark brown overall (Figure 19A), with broad, pale, dorsal stripe running full length of body; leg colour as for body. Paranota on posterior rings present as slight protuberances (Figure 19B). Sternites without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and of similar length to femorite, with noticeable ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid, small prefemoral lip; femorite (F) contributing to c. 1/2 acropodite length in situ, slightly curved when viewed anteriorly, upright and becoming thicker towards apex; main femoral process (MFP): long (to c. 1/4 solenomere length), pointed, but not spine-like, hatchet-shaped; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, generally more slender than femorite but of variable thickness; solenomere tip with single flattened end, broadly pointed, with no serrations; solenomere process (sp1); near solenomere tip, small, pointed, upright, slender (Figures 19C–F).

Female

No female specimens have been collected.

DISTRIBUTION

This species has been collected only from the Marvel Loch area (Figure 37).

ETYMOLOGY

This species is named for Robert Howard of Cliffs Natural Resources in appreciation of his support for this research project.

Antichiropus incomptus **sp. nov.**

Figures 20, 37

http://www.zoobank.org/urn:lsid:zoobank.org:act:B8040C9C-4D46-4B3F-B277-AF022CA15E0B

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , S of Kambalda, 31°34′03″S, 121°44′42″E, April 2006, S. Thompson (WAM T124577).

Paratypes

Australia: ***Western Australia*:** 21 , 6 , 3 juveniles, S of Kambalda, 31°34′03″S, 121°44′42″E, April 2006, S. Thompson (WAM T99989).

Other material

Australia: ***Western Australia*:** 1 , Woodline, 31°57′S, 122°24′E, August 1980, pitfall trap, mallee/shrubs, W.F. Humphreys et al. (WAM T71829); 1 , 1 , S of Kambalda, 31°34′03″S, 121°44′42″E, April 2006, S. Thompson (WAM T112935); Bedourie Hill, c. 47 km NE of Norseman, N of Eyre Highway, 32°03′20.0″S, 122°15′31.1″E, 16 November 2011, under disturbed rocks, remains only, C.A. Car and J.M. Waldock (WAM T119065); Bedourie Hill, c. 47 km NE of Norseman, N of Eyre Highway, 32°03′20.0″S, 122°15′31.1″E, 16 November 2011, under disturbed rocks, remains only, C.A. Car and J.M. Waldock (WAM T119066); 1 (remains only), Bedourie Hill, c. 47 km NE of Norseman, N of Eyre Highway, 32°03′20.0″S, 122°15′31.1″E, 16 November 2011, under disturbed rocks, C.A. Car and J.M. Waldock (WAM T119067); 1 (remains only), Bedourie Hill, c. 47 km NE of Norseman, N of Eyre Highway, 32°03′20.0″S, 122°15′31.1″E, 16 November 2011, under disturbed rocks, C.A. Car and J.M. Waldock (WAM T119068).

DIAGNOSIS

Gonopod: *Antichiropus incomptus* is recognisable by its simple gonopod, with a relatively long femorite. There are no obvious solenomere processes, just one tiny spine near the solenomere tip. This species is most similar to *A. howardi*, but has a relatively slender femorite and short solenomere as well as a differently shaped femoral process (Figures 20C–F).

DESCRIPTION

Male holotype

Body c. 24 mm long; midbody ring c. 2.75 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 20A), with pale paramedian spots on dorsal metazonites, giving a banded appearance; leg colour as for body. Paranota on posterior rings present as slight protuberances (Figure 20B). Some sternites, except ring 5, with posteriorly pointing, setose protuberances, sternite of ring 5 without obvious processes/tubercles, sternal lamella broad, mushroom-shaped. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks at least partially obscuring cardines, when viewed face-on, maximum width c. 3.8 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and shorter than femorite, with noticeable ridge on

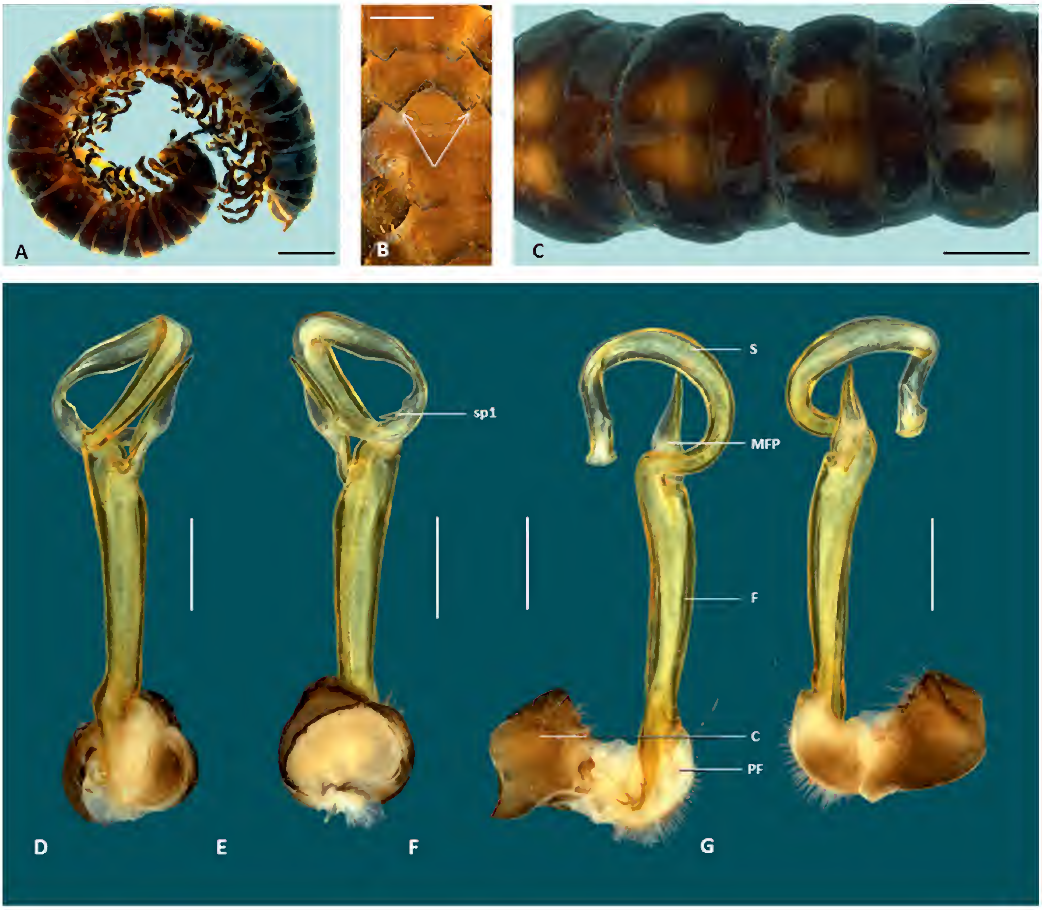

FIGURE 20 *Antichiropus incomptus* sp. nov.: A-C, male (WAM T112935) A, B, habitus: A, lateral view; C, dorsal view; B, sternites showing posteriorly pointing processes (indicated by arrows): D–G, paratype male (WAM T99989) left gonopod: D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 0.5 mm; C = 1 mm; D–G = 0.5 mm.

anterior surface; prefemur (PF) considerably shorter than femorite, ovoid; femorite (F) contributing to c. 2/3 of acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, spear or flame-shaped; femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, generally more slender than femorite, and thickest midway along length; solenomere tip with single, flattened end, with no serrations; solenomere process (sp1): near solenomere tip, small, pointed, slender (Figures 20C–F).

Female

Similar to male, but slightly wider dorsally (c. 3 mm wide) (WAM T112936)

DISTRIBUTION

This species has been collected mainly from rocky outcrops, c. 50 km east of Norseman and from mallee country in Kambalda (Figure 37).

ETYMOLOGY

The species name describes the relatively simple configuration of the male gonopod (Latin, adjective, *incomptus*, unadorned).

Antichiropus inflatus sp. nov.

Figures 21, 38

http://www.zoobank.org/urn:lsid:zoobank.org:act:F69CB601-E70E-4291-8E4E-9BA5AE1C332A

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Mt Hampton Nature Reserve Dam, site MN 6, 31°45′40″S, 119°04′21″E, wet pitfall trap, closed 22 September 1998, N. Guthrie (WAM T72056).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus inflatus* is characterised by a short solenomere with a broad paddle-like tip in close association with a noticeably long solenomere process. In addition, the main femoral process is large and swollen and bulb-like in appearance (Figures 21C–F). This species is very similar to *A. succedaneus* (Figure 33D) but the solenomere tips differ markedly between the species.

DESCRIPTION

Male holotype

Body length c. 30 mm, appearing slightly rugose laterally; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour

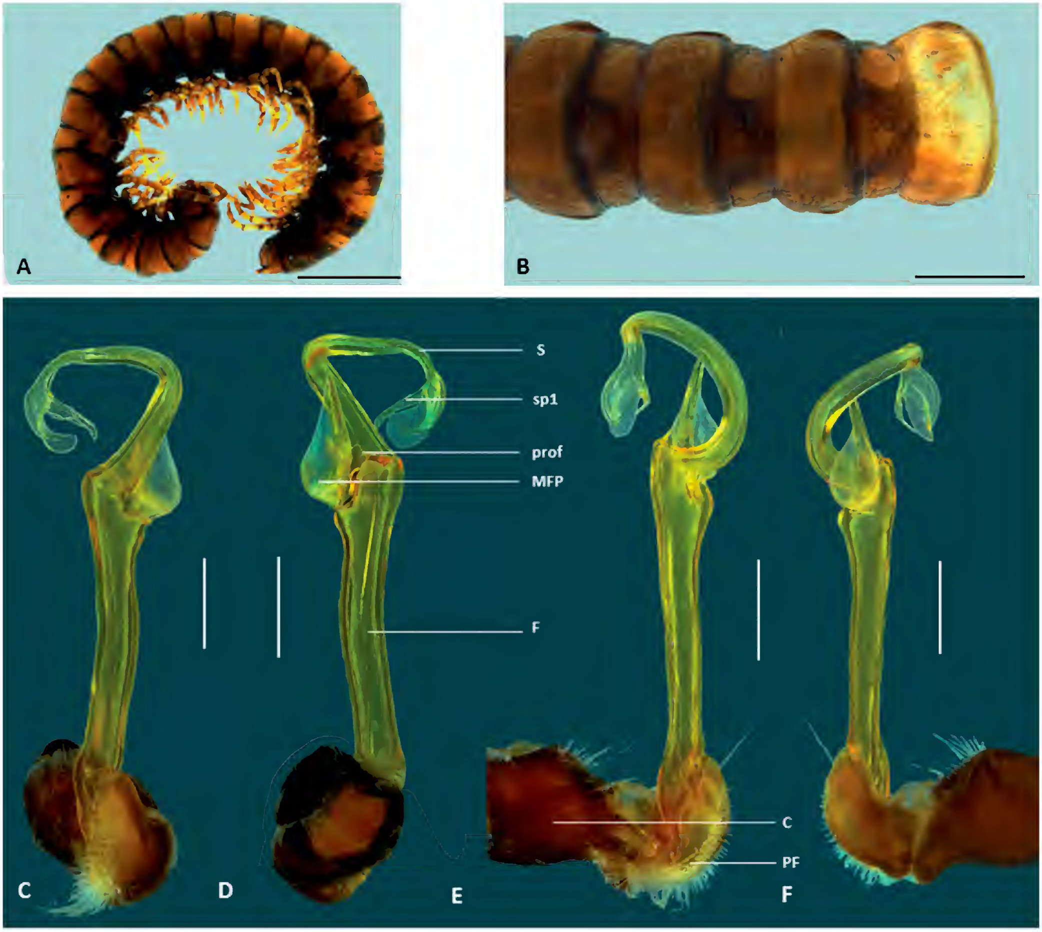

FIGURE 21 *Antichiropus inflatus* sp. nov.: holotype male (WAM T72056) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1, solenomere process 1. Scale bars: A = 5 mm; B = 2 mm; C–F = 0.5 mm.

chestnut brown overall (Figure 21A), with transverse bands; legs noticeably paler than body. Paranota on posterior rings present as slight protuberances (Figure 21B). Sternites, except ring 5, with no noticeable features, sternite of ring 5 with slight protuberances, sternal lamella broad, helmet-shaped. Anterior spiracles at midbody protuberant, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.5 x the distance between antennal sockets; sockets separated by c. 1.5 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge ring 5; coxa (C) more robust, thicker, shorter than femorite, with noticeable ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid; femorite (F) c. 2/3 of acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) stout, very long, to c. 1/2 solenomere length, pointed, bulbous; second femoral process (fp1) absent; prolongation of femorite apex (prof) present as tiny spine; solenomere (S) relatively short, forming circle, generally more slender than femorite, thick at base, becoming thinner midlength, thickening again at tip; solenomere tip broadly flattened and rounded, with no serrations; solenomere process (sp1) near solenomere tip, prominent, pointed, curved, slender (Figures 21C–F).

Female

Females of this species are unknown.

DISTRIBUTION

This species is known from only one male specimen collected from Mt Hampden Nature Reserve (Figure 38)

ETYMOLOGY

The species name describes the appearance of the main femoral process on the male gonopod of this species (Latin, adjective, *inflatus,* swollen).

Antichiropus inopinatus **sp. nov.**

Figures 22, 38

http://www.zoobank.org/urn:lsid:zoobank.org:act:885F0DB0-C4D1-4DB7-A902-043F5D7B74DE

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia***: , Fraser Range Station, water tank hill behind old homestead, 32°01′55.1″S, 122°48′09.5″E, 2 August 2012, J.M. Waldock (WAM T132359).

Paratypes

Australia: ***Western Australia***: 1 , 1 , 1 juvenile, Fraser Range Station, collected with holotype, female and juvenile in eucalypt litter in small gully with mallee, male among rocks near water tank, J.M. Waldock (WAM T126105).

Other material

Australia: ***Western Australia***: 1 , 1 , Fraser Range, 31°57′S, 122°53′E, 1 June 1914, collector unknown (WAM T347; old number 14/1006); 3 , Fraser Range Station, 32°04′S, 122°48′E, 22 April 1995, under rocks, A.F. Longbottom (WAM T71974, T112934); 3 specimens, fragmented remains only (not males), Fraser Range Station, hill behind old homestead, 32°02′59.1″S, 122°48′06.7″E, 16 November 2011, under granite rocks and litter, C.A. Car and J.M. Waldock (WAM T119060, T119061).

DIAGNOSIS

Gonopod: in *Antichiropus inopinatus,* the main femoral process is carried on a shelf-like protuberance on the femorite, similar to those found in *A. anconus* (Figure 7D) and *A. equinus* (Figure 15D), but, in contrast with those two species, the process in this species is uniquely long and slender. The solenomere tip is markedly broad and flat and there are serrations along one edge of the solenomere, closer to its base (Figures 22C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour dark brown with pale dorsal stripe (Figure 22A); leg colour as for body. No paranota on posterior rings (Figure 22C). Sternites without obvious processes/tubercles, sternal lamella broad, mushroom-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.3 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than the proximal ones and relatively slender. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust and thicker than femorite, with slight ridge; prefemur (PF) of similar length to femorite, ovoid, a noticeable prefemoral lip; femorite (F) contributing to c. 1/2 acropodite length in situ, slightly curved when viewed anteriorly, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed, curved; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, short,

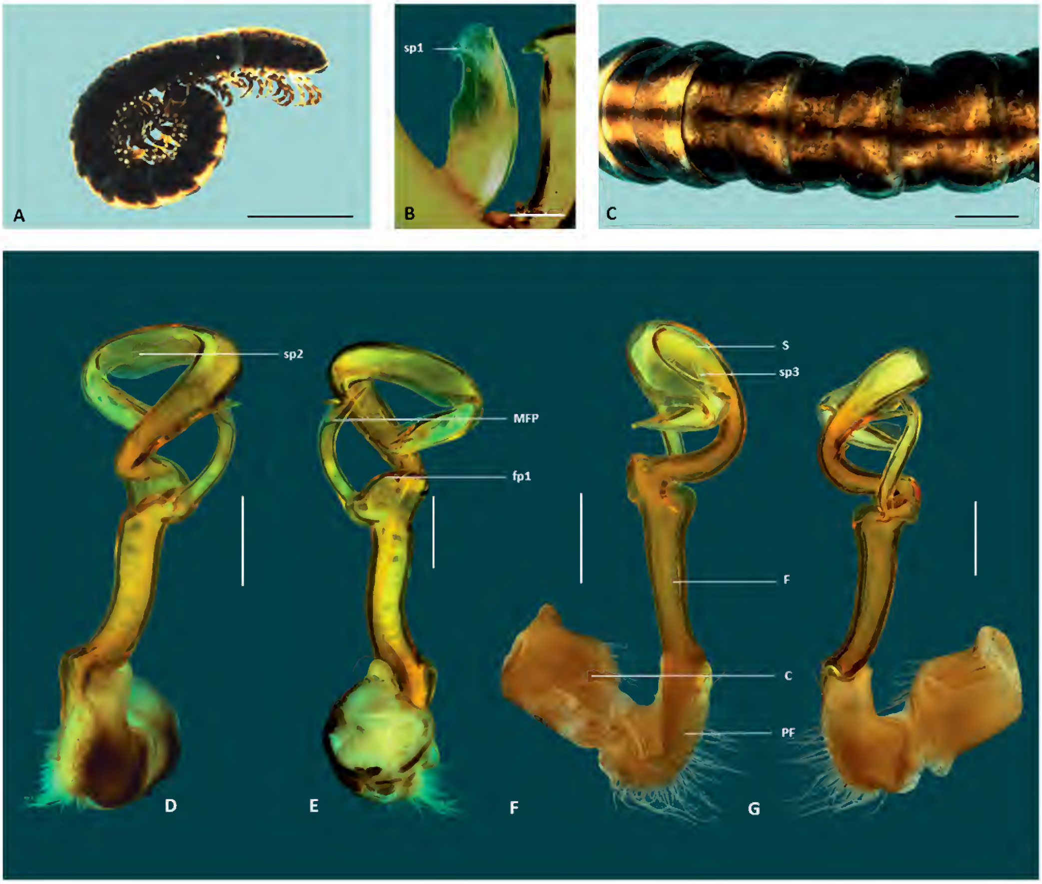

FIGURE 22 *Antichiropus inopinatus* sp. nov. A and C, paratype male (WAM T126105) habitus: A, lateral view; C, dorsal view; B, D and E, holotype male (WAM T132359) left gonopod: B, solenomere tip; D, posterior view; E, anterior view; F and G, male (WAM T112934) left gonopod: F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1, sp2 and sp3, solenomere processes 1, 2 and 3. Scale bars: A = 5 mm; B = 0.2 mm; C = 2 mm; D–G = 0.5 mm.

triangular; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, mainly thicker than femorite, thinnest at base, then thicker, small serrations near base; solenomere with single slightly ridged flattened tip and minute process (spl) (Figure 22B); second solenomere process (sp2) closer to solenomere tip than base, prominent, pointed, upright, slender; third solenomere process (sp3) in basal third of solenomere, prominent, pointed (Figures 22D–G).

Female

Of similar length and colour to male but broader, c. 2.5 mm wide dorsally (WAM T126105).

DISTRIBUTION

This species is known only from a hill behind the old homestead on Fraser Range Station, east of Norseman (Figure 38).

ETYMOLOGY

This species is named for its being found on an exposed hillside in semi-arid country (Latin, adjective, *inopinatus*, unexpected).

Antichiropus kealleyi sp. nov.

Figures 23, 38

http://www.zoobank.org/urn:lsid:zoobank.org:act:94EBED04-A789-440C-AAA8-AC8CFE6FACF1

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Koolyanobbing Range, 30°48′S, 119°35′E, 31 July 2007, beneath rocks of ironstone hills, M. Bamford (WAM T82459).

Paratypes

Australia: ***Western Australia:*** 1 , 3 , collected with holotype (WAM T67126).

Other material

Australia: ***Western Australia:*** 2 , 3.4 km SE of Koolyanobbing, 30°50′27.49″S, 119°32′27.56″E, 23 August 2009, leaf litter, R. Teale (WAM T99038, T99055); 1 , 2 , 11.0 km SE of Koolyanobbing, 30°52′29.68″S, 119°36′37.01″E, 22 August 2009, leaf litter, R. Teale (WAM T99073, T112940).

DIAGNOSIS

Gonopod: *Antichiropus kealleyi* may be easily recognised by the shape of the two femoral processes on the short squat gonopod femorite: the processes are very similar in length, thickness, shape and orientation to each other (Figure 23E). The femorite prolongation consists of two tiny sub-equal spines (Figures 23B).

FIGURE 23 *Antichiropus kealleyi* sp. nov.: male (WAM T99055) habitus: A, lateral view; B, dorsal view; C–F, holotype male (WAM T82459) left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 1 mm.

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown, almost black (Figure 23A); leg colour as for body. No paranota on posterior rings (Figure 23C). Sternites, except ring 5, with slight protuberances carrying long setae on some, sternite of ring 5 with processes, sternal lamella broad, heart-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.6 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod relatively longer, reaching anterior edge of ring 5; coxa (C) more robust, thicker, of similar length to femorite, with noticeable ridge on anterior surface; prefemur (PF) somewhat shorter than femorite; femorite (F) contributing to c. 1/2 acropodite length in situ, curved, robust, and becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed; second femoral process (fp1) present, arising close to solenomere base, following curve of MFP, pointed, slender along its length; prolongation of femorite apex (prof) present as two tiny spines; solenomere (S) long, forming >1 loop/circle, generally more slender than femorite, thick at base, thin at tip; solenomere tip pointed, with no serrations; solenomere process (sp1) near solenomere tip, small, pointed, slender; second solenomere process (sp2) near solenomere base, prominent, pointed, triangular (Figures 23C–F).

Female

Of similar length and colour to the male but noticeably broader, c. 3 mm wide dorsally (WAM T67126).

DISTRIBUTION

All specimens of this species were collected from Koolyanobbing, from under rocks or in leaf litter (Figure 38).

ETYMOLOGY

This species is named for Ian Kealley, Regional Manager of the Department of Parks and Wildlife's Goldfields Region, in recognition of his ongoing efforts to support biodiversity research in Western Australia.

Antichiropus lacustrinus **sp. nov.**

Figures 24, 38

http://www.zoobank.org/urn:lsid:zoobank.org:act:851FFC20-597A-4CFF-B5EE-47B2893A5546

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Lake King-Norseman Road, site LK13, 33°04′54″S, 119°59′53″E, 15 October 1999–25 October 2000, wet pitfall trap, N. Guthrie (WAM T124607).

Paratypes

Australia: ***Western Australia*:** 1 , Bungalbin Hill, 37 km N of Koolyanobbing, 30°30′28.92″S, 119°35′47.31″E, 3–11 April 2013, litter, S. White, A. Heidrich, A. Nowicki, J. Vos, F. Bokhari (WAM T130686).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus lacustrinus* is most similar to *A. axicius* (Figure 8C–F), both with a noticeably short squat femorite, but that of *A. lacustrinus* is shorter and more curved when viewed anteriorly and its solenomere is relatively thicker at the base than that of *A. axicius*. The shape of the main femoral process differs noticeably in the two species (Figures 24C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring with distinct waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 24A), with 2 pale dorsal stripes, running full length of body; legs with coloration similar to that of main body. No paranota on posterior rings (Figure 24B). Sternites, except ring 5, with setose protuberances on some, setae long; sternite of ring 5 without obvious processes/tubercles, sternal cross impressions of similar depth, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2.5 x width of socket. Antennae distinctly clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, of similar length to femorite; Prefemur (PF) of similar length to femorite,

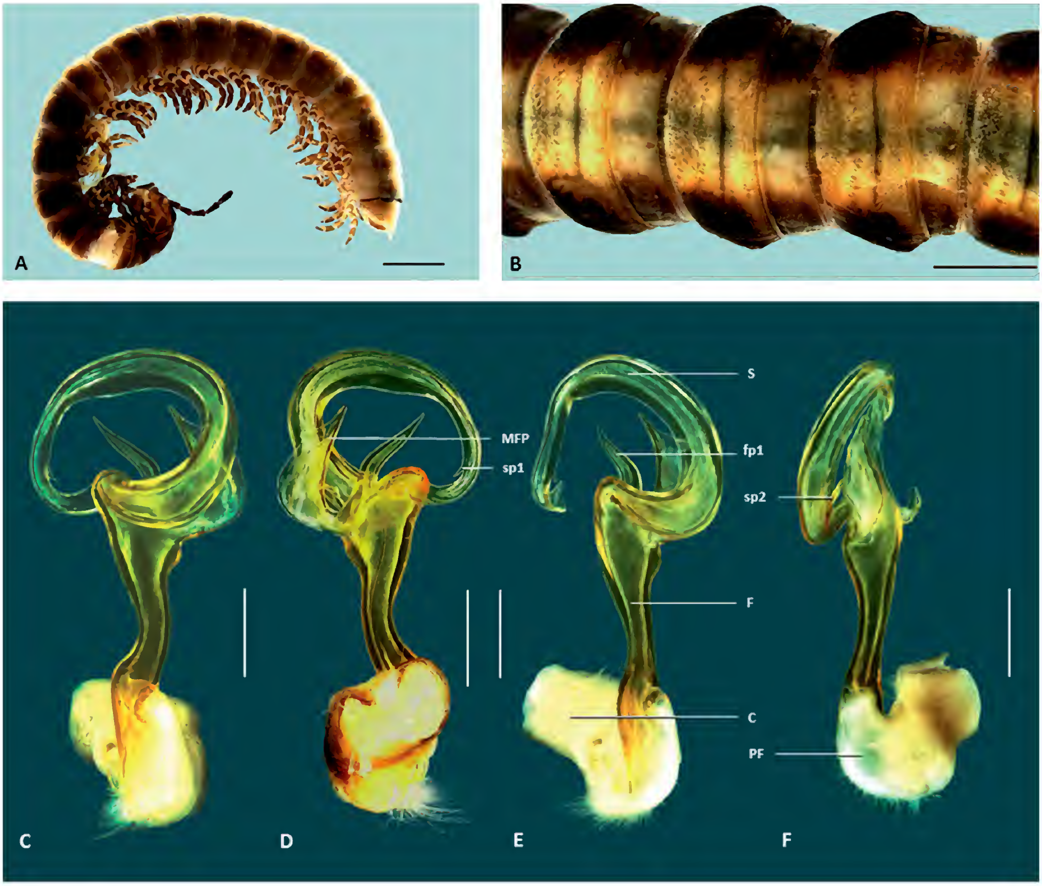

FIGURE 24 *Antichiropus lacustrinus* sp. nov.: holotype male (WAM T124607) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

ovoid, small prefemoral lip; femorite (F) contributing to c. 1/2 acropodite length in situ, curved, broadening into large rounded protuberance from which main femoral process (MFP) arises, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, carried on large femoral protuberance held at right angles to femorite; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, of variable thickness, thick at base, becoming thinner mid-length, thickening again at tip; solenomere tip broadly pointed, with no serrations, single flattened end; solenomere process (sp1) near solenomere tip, small, pointed; second solenomere process (sp2) near solenomere base, prominent, pointed (Figures 24C–F).

Female

No female specimens have been collected.

DISTRIBUTION

Only three males and three juveniles of this species have been collected from Marvel Loch (Figure 38).

ETYMOLOGY

This species is named for its occurrence near a lake (Latin, *lacustrinus*, of lakes).

Antichiropus laticlavius **sp. nov.**

Figures 25, 39

http://www.zoobank.org/urn:lsid:zoobank.org:act:C14632B1-DF05-455D-A786-BB74D1853E6D

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , McDougall Nature Reserve, site DU 09, 33°27′08″S, 118°06′57″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T72007).

Paratypes

Australia: ***Western Australia***: 4 , 2 , Dunn Rock Nature Reserve, N of farm, site LK 5, 33°14′49″S, 119°33′04″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T72005).

Other material

Australia: ***Western Australia*:** 1 , collected with paratypes (WAM T72006); 1 , 2 juveniles, adjacent to Holland Rock Nature Reserve, site PI 5, 33°21′35″S, 118°44′50″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T72008); 1 , granite rock N of Koorda-Bullfinch Road, W of Warrachuppin Road, 31°00′35″S, 118°42′02″E, 25 June 2006, under granite rocks on outcrop, J.M. Waldock, R. Engel, R and R. Morritt (WAM T74820); 1 , as above (WAM T76739); 1 , Baladjie Rock, western slopes, 30°57′13.2″S, 118°52′33.5″E, 3 June 2007, under granite rocks along edge, J.M. Waldock (WAM T85344);1 , 1 , as above (WAM T85345); 1 , N of farm, Dunn Rock nature Reserve, site LK5, 33°14′49″S, 119°33′04″E, 15 October 1999–1 November 2000, wet pitfalls, P. Van Heurck et al.(WAM T114009).

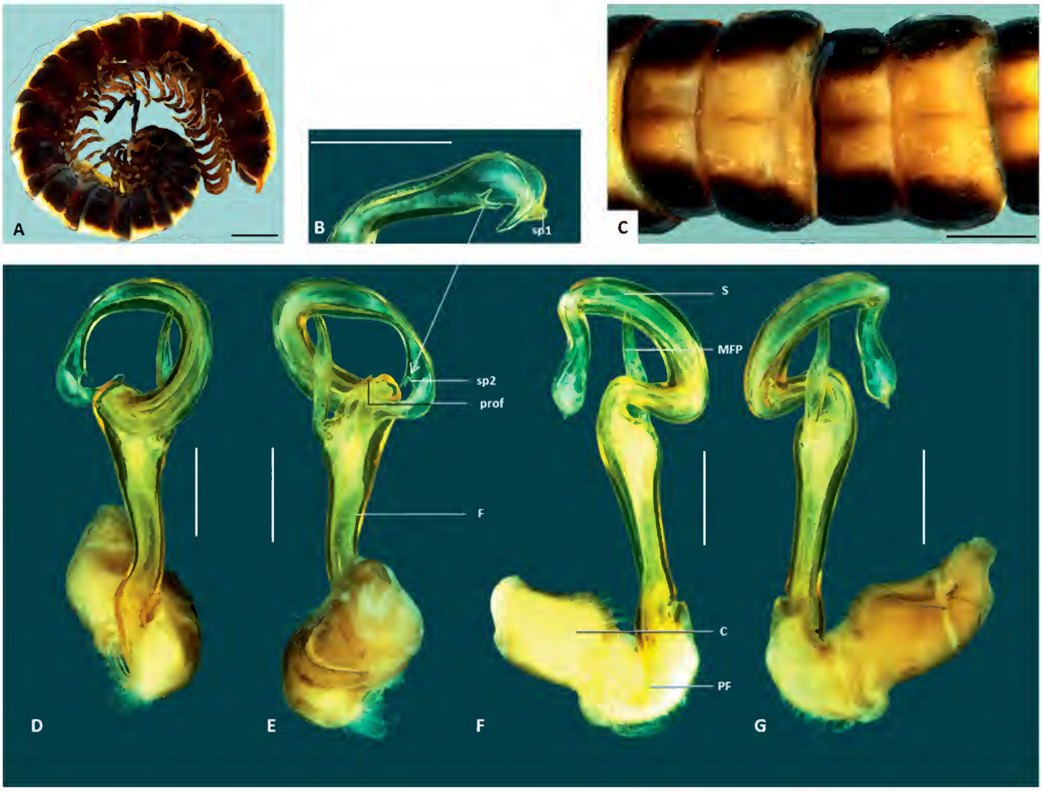

FIGURE 25 *Antichiropus laticlavius* sp. nov.: A and C male from west of Warrachuppin Rd (WAM T76739) habitus: A, lateral view; C, dorsal view; B and D–G, holotype male (WAM T72007) left gonopod: B, solenomere tip; D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 0.5 mm; C = 1 mm; D–G = 0.5 mm.

DIAGNOSIS

General: the broad dorsal stripe on this species assists in its identification (Figure 25C).

Gonopod: *Antichiropus laticlavius* has a robust solenomere with a combination of two features making identification relatively simple, namely, the presence of small serrations near the base of the solenomere and a distinctive two-pronged second process near the tip of the solenomere (Figures 25B, D–G).

DESCRIPTION

Male holotype

Body c. 25 mm long, slightly rugose laterally; midbody ring c. 2.5 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 25A), with broad, pale, dorsal stripe running full length of body (Figure 25C); leg colour as for body. No paranota on posterior rings. Some sternites, except ring 5, with slight protuberances bearing long setae, sternite of ring 5 without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks at least partially obscuring cardines, when viewed face-on; maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, clavate, antennomeres relatively robust. Collum 0.75 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, of similar length to femorite, with slight ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid, appearing to hug femorite base; femorite (F) contributing to c. 1/2 acropodite length in situ, slightly curved when viewed anteriorly, broadening into large, rounded protuberance from which main femoral process arises, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, spear or flame-shaped; second femoral process (fp1) absent; prolongation of femorite apex (prof) present as tiny spine; solenomere (S) long, forming >1 loop/circle, mainly thicker than femorite, thick at base, becoming thinner mid-length, thickening again at tip; solenomere tip broadly pointed, with no serrations; solenomere process (sp1) near solenomere tip, tiny, pointed, triangular; second solenomere process (sp2) in apical 1/3 of solenomere, small, pointed with two branches (Figures B, D–G).

Female

Similar to male but more robust, midbody dorsal width c. 3 mm (WAM T72005).

DISTRIBUTION

This species is known from several localities on the western edge of the Great Western Woodlands, ranging from c. 31° to 33°S (Figure 39).

ETYMOLOGY

This species is named for its longitudinal dorsal stripe (Latin, *laticlavius,* having a broad stripe).

Antichiropus nadineae **sp. nov.**

Figures 26, 39

http://www.zoobank.org/urn:lsid:zoobank.org:act:0D0B3B4F-A8EF-4189-B762-428DCF41EA7D

MATERIAL EXAMINED

Holotype

Australia: *Western Australia*: , Credo Station, c. 17 km NW of Homestead, 30°20′47.7″S, 120°42′23.2″E, 3 September 2011, M.S. Harvey et al. (WAM T119044).

Other material

Australia: *Western Australia*: 1 , Credo Station c. 55 km NNW of Homestead, 29°58′59.3″S, 120°40′19.4″E, 3 September 2011, M.S. Harvey (WAM T118635).

DIAGNOSIS

Gonopod: the two species most similar to *Antichiropus nadineae* are *A. serratus* (Figures 31C–F) and *A. westi* (Figures 34C–F) with both the main and second femoral processes being similar in configuration in all three species. A. *serratus* may, however, be separated by its prominent serrations at the base of the broad based solenomere and its short squat femur: both *A. nadineae* and *A. westi* have solenomeres with no serrations and with slender bases, but may be determined from each other by the shape of the femur, the main femoral process and the length of the second femoral process. *A. nadineae* also has a small prolongation of the femur, lacking in *A. westi* (Figure 26F).

DESCRIPTION

Male holotype

Body c. 20 mm long; midbody ring c. 2 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour dark brown, almost black (Figure 26A); leg colour as for body. No paranota on posterior rings (Figure 26B). Sternites without obvious processes/tubercles, sternal lamella broad, with straight edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on; maximum width c. 3.7 x the distance between antennal sockets; sockets separated by c. 1.6 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones, relatively slender. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, of similar length to

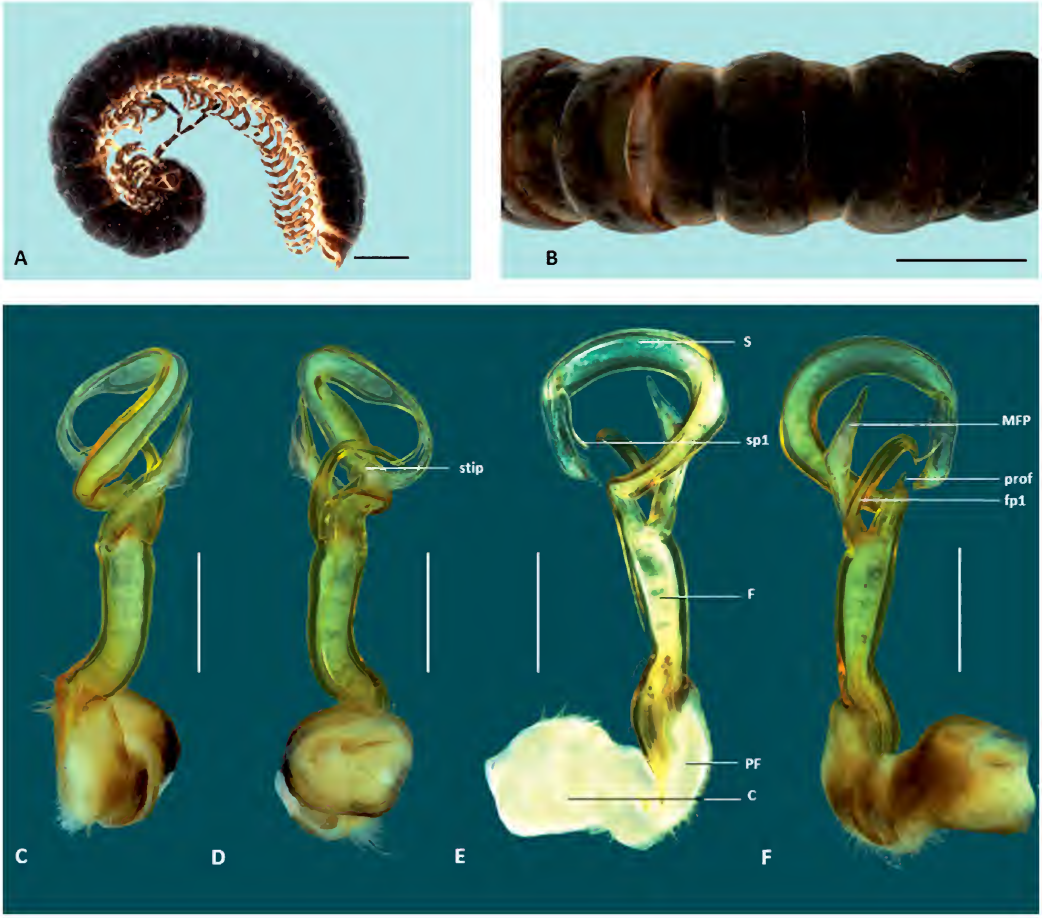

FIGURE 26 *Antichiropus nadineae* sp. nov.: holotype male (WAM T119044) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1, solenomere process 1; stip, solenomere tip. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

femorite, with slight ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid, appearing to hug femorite base; femorite (F) c. 1/2 acropodite length in situ, slightly curved when viewed anteriorly, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, hatchet-shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, slender along length; prolongation of femorite apex (prof) present, small, triangular and sharply pointed; solenomere (S) long, forming >1 loop/circle, generally more slender than femorite, of variable thickness; solenomere tip broadly flattened, with no serrations; solenomere process (sp1) near solenomere tip, prominent, pointed, upright, slender (Figures 26C–F).

Female

Similar to male in colour and length but broader, c. 2.5 mm wide dorsally (WAM T118635).

DISTRIBUTION

The species is known from just one male and one female collected from the base of a tree at Credo Station, 70 km north of Coolgardie (Figure 39).

ETYMOLOGY

The species epithet is a patronym in honour of Nadine Guthrie who has collected numerous *Antichiropus* specimens.

Antichiropus paracalothamnus **sp. nov.**

Figures 27, 39

http://www.zoobank.org/urn:lsid:zoobank.org:act:92D58326-3C9E-4947-A750-920C27849032

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , McDermid Rock, Hyden-Norseman Road, 32°01′12.5″S, 120°44′23.3″E, 21 September 2011, in deep damp *Calothamnus tuberosus* litter on outcrop, J.M. Waldock and C.A. Car (WAM T124574).

Paratypes

Australia: ***Western Australia:*** 2 , 1 juvenile, collected with holotype (WAM T115026)

Other material

Australia: ***Western Australia:*** 1 , McDermid Rock, Hyden-Norseman Road, 32°01′12.5″S, 120°44′23.3″E, 21 September 2011, in deep damp *Calothamnus tuberosus* litter on outcrop, J.M. Waldock and C.A. Car (WAM T115036); 1 , 2 juveniles, Disappointment Rock, Hyden-Norseman Road, 32°07′49.7″S, 120°55′40.6″E, 21 September 2011, in deep damp *Calothamnus tuberosus* litter on outcrop, J.M. Waldock and C.A. Car (WAM T115128); 1 , McDermid Rock, Hyden-Norseman Road, 32°01′12.5″S, 120°44′23.3″E, 21 September 2011,

FIGURE 27 *Antichiropus paracalothamnus* sp. nov.: paratype male (WAM T115026) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; serr, serrations; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

in deep damp *Calothamnus tuberosus* litter on outcrop, J.M. Waldock and C.A. Car (WAM T115130); 3 , 2 , 3 juveniles, Disappointment Rock, Hyden-Norseman Road, 32°07′49.7″S, 120°55′40.6″E, 21 September 2011, in deep damp *Calothamnus tuberosus* litter on outcrop, J.M. Waldock and C.A. Car (WAM T115141, T115143, T115144).

DIAGNOSIS

Gonopod: *Antichiropus paracalothamnus* is unmistakeable. The most remarkable feature of the gonopod is the cowl-like appearance of the solenomere midway along its length: it then thins abruptly towards the tip where it expands again into a tongue-like structure (Figures 27C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown, almost black (Figure 27A); leg colour as for body. Paranota on posterior rings present as slight protuberances (Figure 27B). Sternites without obvious processes/tubercles, sternal lamella broad, heart-shaped. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.5 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively slender. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, shorter than femorite, with slight ridge; prefemur (PF) somewhat shorter than femorite, appearing to hug femorite base; femorite (F) c. 2/3 of acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, slender along length; prolongation of femorite apex (prof) absent; solenomere (S) held in different plane from femorite i.e. in Figure 27D, femorite is shown as vertical and solenomere appears orientated horizontally; long, forming >1 loop/circle, mainly thicker than femorite, thickest midway along length, slight serrations near base; solenomere tip flattened, with no serrations, tongue-like; solenomere process (sp1) positioned c. halfway along solenomere, small, pointed, upright, slender (Figures 27C–F).

Female

Similar to male, but slightly broader, slightly less than 3 mm wide dorsally (WAM T115144).

DISTRIBUTION

This species was collected at two sites, both granite outcrops, known as Disappointment Rock and McDermid Rock, in the south west corner of the Goldfields. All specimens were found hidden in the damp leaf litter at the base of the shrub *Calothamnus tuberosus,* clinging to granite outcrops and well known for the water retaining capabilities of its roots (Figure 39).

ETYMOLOGY

As this species was collected only from the leaf litter at the bases of *Calothamnus tuberosus* shrubs it was named accordingly (Greek, prefix, *para,* next to; adjective, *kalos,* beautiful; noun, *thamnos,* shrub).

Antichiropus rex **sp. nov.**

Figures 28, 40

http://www.zoobank.org/urn:lsid:zoobank.org:act:629C70AF-112E-41DE-9168-77A1F56D2341

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , N of Edwards Road, SE of Lake King, site GP 2, 33°22′01″S, 120°59′43″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T80933).

Paratypes

Australia: ***Western Australia*****:** 1 , collected with holotype (WAM T72564); 4 , remains only collected with holotype (WAM T72565).

Other material

Australia: ***Western Australia*****:** 1 , 2 , 1 juvenile, 'Sieda', E of Grass Patch, 33°14′S, 121°46′E, 8 May 2005, E of '10 Bugger' dam, in heavy, damp litter, mallee bush, A.F. Longbottom (WAM T66526, T66527); 1 , 'Sieda' (Fitz. Loc. 41), E of Grass Patch, 33°14′S, 121°46′E, 24 April 2006, in litter at rubbish tip, A.F. Longbottom (WAM T66711); 2 , 5 juveniles, N of Edwards Road, SE of Lake King, site GP 2, 33°22′01″S, 120°59′43″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T72563); 4 , 8 , 10 juveniles (damaged specimens), W of Dalyup Road, W of Scaddan, site GP 8, 33°23′09″S, 121°34′56″E, 15 October 1999–1 November 2000, wet pitfall, P. Van Heurck et al. (WAM T72566).

DIAGNOSIS

Gonopod: *Antichiropus rex* is similar to others that have a large spoon-shaped apex to the solenomere: *A. cavernus* (Figures 11C–F), *A. simpulus* (Figures 32D–G) and *A. mammillifer.* It is easily distinguished from *A. cavernus* and *A. mammillifer* by lacking the bulbous second femoral process they carry, and from *A. simpulus* by the lack of serrations on the main femoral process. In addition, *A. rex* has a very short, thick femorite and the solenomere becomes very stout before it extends into the spoon-shaped apex (Figures 28C–F).

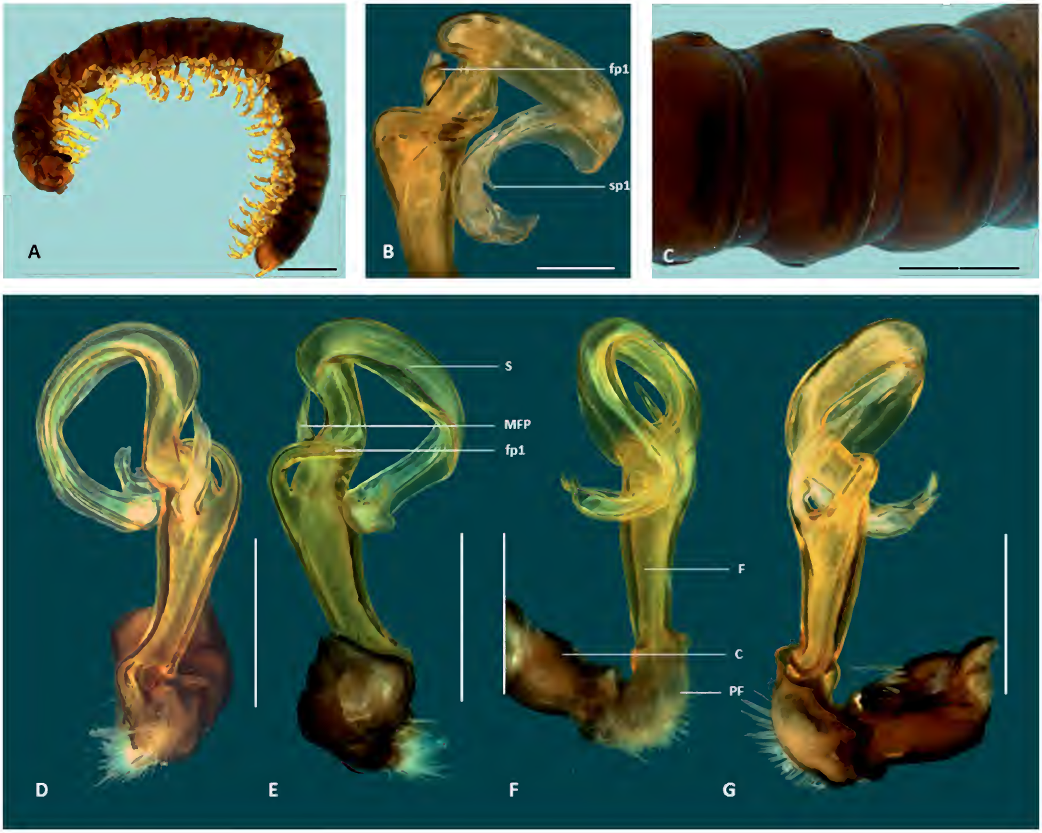

FIGURE 28 *Antichiropus rex* sp. nov.: A and C paratype male (WAM T72564) habitus: A, lateral view; C, dorsal view; B and D–G, paratype male (WAM T72565) left gonopod: B, solenomere tip; D, posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 0.2 mm; C = 1 mm; D–G = 0.5 mm.

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 28A); legs noticeably paler than body. Paranota on posterior rings present as slight protuberances (Figure 28C). Sternites without obvious processes/tubercles, transverse and longitudinal cross impressions of similar depth, sternal lamella relatively narrow, with rounded edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.6 x the distance between antennal sockets; sockets separated by c. 1.5 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) similar in thickness and length to femorite, with slight ridge on anterior surface; prefemur (PF) of similar length to femorite, ovoid, appearing to hug femorite base; femorite (F) c. 1/2 acropodite length in situ, curved, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, spear or flame-shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, slender along length; prolongation of femorite apex (prof) absent; solenomere (S) long, forming >1 loop/circle, generally as thick as femorite, of similar thickness along length but thickest nearer tip; solenomere tip flattened, with no serrations, distinctive spoon-shaped apex; solenomere process (spl) near solenomere tip, tiny, pointed, upright, slender (Figures 28B, D–G).

Female

Similar to male in length, but the specimen examined (WAM T66527) was much paler in colour with dark legs and was much wider (c. 3 mm wide).

DISTRIBUTION

This species has been collected by hand from damp leaf litter at Grass Patch and in wet pitfall traps near Lake King (Figure 40).

ETYMOLOGY

This species name reflects the fact that specimens were first found at Lake King (Latin, noun, *rex*, king).

Antichiropus sagittulus **sp. nov.**

Figures 29, 39

http://www.zoobank.org/urn:lsid:zoobank.org:act:C79FDE8D-B0F3-44C8-81E2-694D9C5B19E8

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*****:** , Mt Gibson Station, site 11, 29°34′52″S, 117°24′15″E, 20–31 August 2001, dry pitfall traps, Biological Survey (WAM T65497).

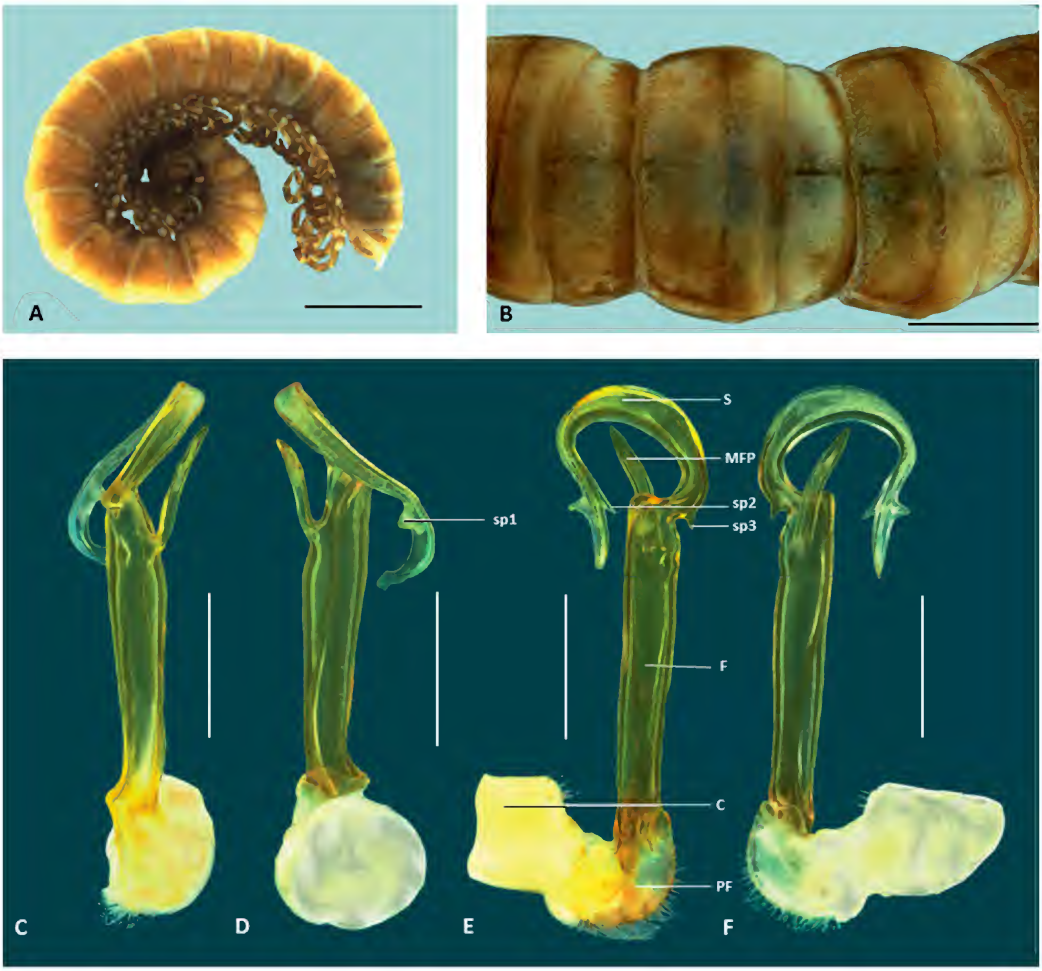

FIGURE 29 *Antichiropus sagittulus* sp. nov.: paratype male (WAM T65498) habitus: A, lateral view; B, dorsal view; C–F, holotype male (WAM T65497) left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; S, solenomere; sp1, sp2 and sp3, solenomere processes 1, 2 and 3. Scale bars: A = 5 mm; B = 1 mm; C–F = 0.5 mm.

Paratypes

Australia: ***Western Australia*:** 2 , collected with holotype (WAM T65498).

Other material

Australia: ***Western Australia*:** 1 , Mt Gibson Station at 29°38′07″S, 117°29′38″E, 28 August 2001, sheoak/wattle woodland, found dead on rocky slope, A. Baynes (WAM T65499); 4 , 3 , Mt Gibson Station at 29°34′52″S, 117°24′15″E, 15 November 2001, dead at base of pitline 11 fence, J. Mead and A. Baynes (WAM T65524).

DIAGNOSIS

General: this millipede is notably large (Figure 29A). Gonopod: *Antichiropus sagittulus* is characterised by the relatively long, straight-sided femorite of its gonopod which immediately separates it from the similar *A. giganteus* (Figure 18), by the small posteriorly facing triangular process at the base of the solenomere and by two processes on opposite sides of the solenomere near its tip (Figure 29E).

DESCRIPTION

Male holotype

Body c. 2.5 mm long; midbody ring slightly less than 3 mm wide dorsally, with distinct waist, prozonite and metazonite of similar width. Colour uniformly pale (Figure 29A); leg colour as for body. No paranota on posterior rings (Figure 29B). Sternites without obvious processes/tubercles, sternal lamella broad, square. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on; maximum width c. 3.5 x the distance between antennal sockets; sockets separated by c. 1.6 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate. Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and shorter than femorite, with slight ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid, appearing to hug femorite base; femorite (F) c. 2/3 of acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), narrow, pointed, finger-like; second femoral process (fp1) absent; prolongation of femorite apex (prof) absent; solenomere (S) long, forming >1 loop/circle, generally more slender than femorite, thickest midway along length; solenomere tip with single flattened end and no serrations; solenomere process (sp1) closer to solenomere tip than base, small, pointed, upright, slender; second solenomere process (sp2) in apical third of solenomere, small, pointed; third solenomere process (sp3) near solenomere base, small, pointed (Figures 29C–F).

Female

Similar to the male in colour and length but broader, c. 3 mm wide dorsally (WAM T65498).

DISTRIBUTION

Several specimens of this species have been collected in dry pitfall traps from Mt Gibson Station only (Figure 39).

ETYMOLOGY

This species name refers to the shape of the solenomere tip on the gonopod (Latin, noun, *sagittulus*, little arrow).

Antichiropus saxatilis **sp. nov.**

Figures 30, 39

http://www.zoobank.org/urn:lsid:zoobank.org:act:69DBD14E-CD19-4181-AFF6-27903FB4A568

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Boorabbin National Park, Boorabbin Rock at dam wall, 31°12′17.7″S, 119°17′22.7″E, 23 September 2011, damp she oak litter, J.M. Waldock and C.A. Car (WAM T124576).

Paratypes

Australia: ***Western Australia:*** 3 , collected with holotype (WAM T115021); 1 , Boorabbin, BNR 1, *Callitris* heath isolate, 31°15′S, 120°04′E, July 1980, pitfall trap, W.F. Humphreys et al. (WAM T71811).

Other material

Australia: ***Western Australia:*** 1 , Boorabbin, BNR 1, *Callitris* heath isolate, 31°15′S, 120°04′E, July 1980, pitfall trap, A1 debris, W.F. Humphreys et al. (WAM T71812); 1 , as above (WAM T71813); 1 , Boorabbin, BNR 3, samphire-lithic complex, 31°14′S, 120°19′E, July 1980, debris, W.F. Humphreys et al. (WAM T71814) 2 , 1 juvenile, Boorabbin, BNR 5, lithic complex, 31°13′S, 120°19′E, July 1980, debris, W.F. Humphreys et al. (WAM T71815, T112929) 1 , Boondi Rock, Goldfields Woodlands National Park, Great Eastern Highway, 31°10′48.8″S, 120°22′58.7″E, 19 September 2011, J.M. Waldock and C.A. Car (WAM T115001); 1 , Boondi Rock, as above collected dead in litter at base of rock (WAM T115155); 1 , Boorabbin National Park, Boorabbin Rock at dam wall, 31°12′17.7″S, 119°17′22.7″E, 19 September 2011, damp she oak litter, J.M. Waldock and C.A. Car (WAM T115022).

DIAGNOSIS

Gonopod: *Antichiropus saxatilis* is similar to that of *A. westi* (Figures 34C–F) and *A. serratus* (Figures 31C–F) but has three solenomere processes, compared with two and one respectively in the other species. The process nearest the tip is relatively large and curved and the third process is a short, pointed spine found in the basal third of the solenomere (Figures 30C–F).

DESCRIPTION

Male holotype

Body c. 22 mm long; midbody ring c. 2 mm wide,

FIGURE 30 *Antichiropus saxatilis* sp. nov.: paratype male (WAM T71811) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; sp1, sp2 and sp3, solenomere processes 1,2 and 3. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

with distinct beaded waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 30A); leg colour as for body. Paranota on posterior rings present as slight protuberances (Figure 30B). Sternites, without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on; maximum width c. 3 x the distance between antennal sockets; sockets separated by c. 2.5 x width of socket. Antennae of moderate length, reaching to body ring 2, distinctly clavate. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, shorter than femorite, with slight ridge on anterior surface; prefemur (PF) somewhat shorter than femorite; femorite (F) c. 1/2 acropodite length in situ, upright, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, hatchet-shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, banana-shaped; prolongation of femorite apex (prof) absent; solenomere (S) long, forming >1 loop/circle, generally more slender than femorite, thickest midway along length; solenomere tip pointed, with no serrations; solenomere process (sp1) near solenomere tip, prominent, pointed, curved, slender; second solenomere process (sp2) positioned in basal 1/3 of solenomere, prominent, pointed; third solenomere process (sp3) near

solenomere base, small, pointed (Figures 30C–F).

Female

Similar to male, but slightly larger and noticeably broader (2.5 mm) (WAM T112929)

DISTRIBUTION

This species has been collected from Boondi Rock and Boorabbin Rock, large granite outcrops on the edge of the Great Eastern highway between Southern Cross and Coolgardie. All specimens were collected by hand either at the base of the rock in damp litter or in the litter of the woodlands growing at the base of the rocks (Figure 39).

REMARKS

The small process near the base of the solenomere appears to vary in size and is more pronounced in some specimens than that shown (Figures 30C–F).

ETYMOLOGY

This species has been found only in association with granite outcrops and its name reflects this association (Latin, *saxatilis,* found among rocks).

Antichiropus serratus **sp. nov.**

Figures 31, 40

http://www.zoobank.org/urn:lsid:zoobank.org:act:C872CC57-A7AC-4C02-A2B0-9569DCD29FAF

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Marvel Loch, St Barbara Operation, Burbidge area, site 9, 31°33′33″S, 119°34′06″E, 30 July 2008, leaf litter, P. Cullen and P. Langlands (WAM T96076).

Paratypes

Australia: ***Western Australia*:** 2 , 1 , Marvel Loch, St Barbara Operation, Edwards Find, site 12, 31°34′35″S, 119°24′09″E, 2 August 2008, under rock, P. Cullen and

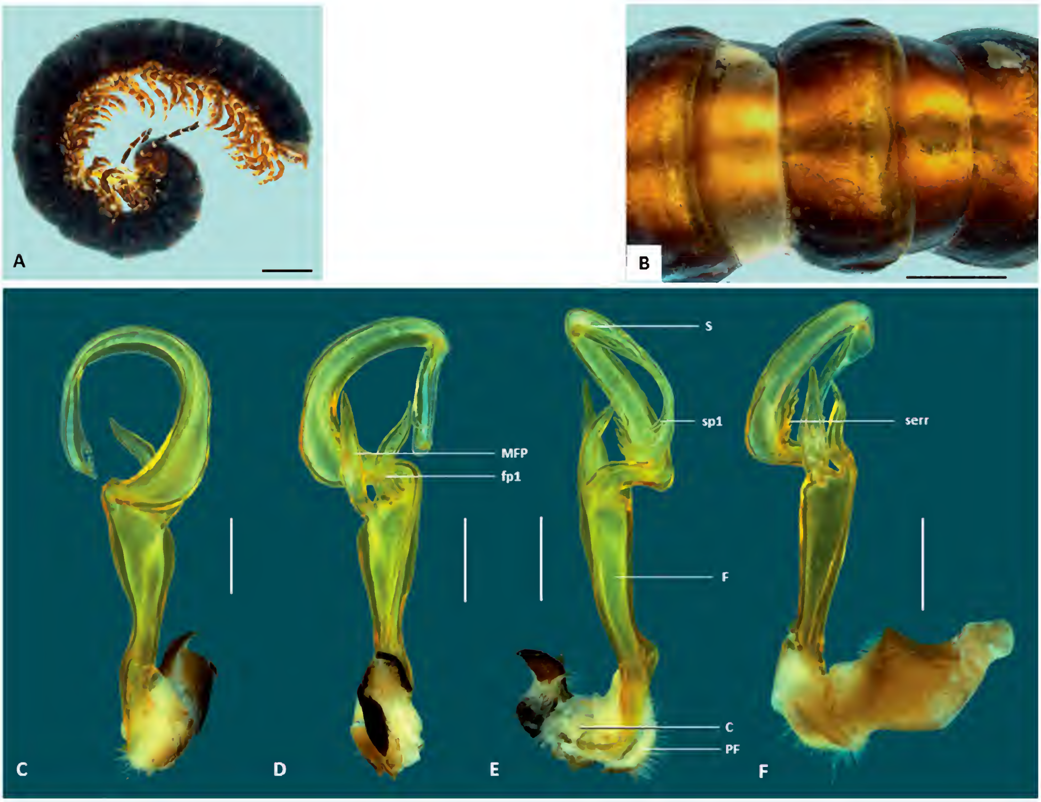

FIGURE 31 *Antichiropus serratus* sp. nov. holotype male (WAM T96076) habitus: A, lateral view; B, dorsal view; C-E, left gonopod: C, posterior view; D, anterior view; E, medial view; F, right gonopod [flipped image] (WAM T96078) lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; serr, serrations; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm

P. Langlands (WAM T96082).

Other material

Australia: ***Western Australia*:** 1 , Marvel Loch, St Barbara Operation, Transvaal area, site 6, 31°15′15″S, 119°18′49″E, 28 July 2008, under log, P. Cullen and P. Langlands (WAM T96071); 1 , Marvel Loch, St Barbara Operation, Edwards Find, site 14, 31°33′33″S, 119°23′50″E, 2 August 2008, under rock, P. Cullen and P. Langlands (WAM T96074); 1 (gonopods damaged), Marvel Loch, St Barbara Operation, Transvaal area, site 6, 31°15′15″S, 119°18′48″E, 29 July 2008, leaf litter, P. Cullen and P. Langlands (WAM T96078).

DIAGNOSIS

Gonopod: the diagnostic feature of *Antichiropus serratus* is a noticeable serrated process (Figure 31F) at the thickest section of the solenomere, close to its base. The species is similar to *A. westi* but aside from serrations, it has a shorter and more robust femorite, and a thicker solenomere base than *A. westi*.

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct beaded waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 31A), with 2 pale, dorsal stripes, running full length of body; leg colour as for body. Paranota on posterior rings present as slight protuberances (Figure 31B). Sternites without obvious processes/tubercles, sternal lamella broad, with rounded edge. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on; maximum width c. 3.3 x the distance between antennal sockets; sockets separated by c. 2.2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) thicker, but of similar length to femorite; prefemur (PF) considerably shorter than femorite, ovoid, appearing to hug femorite; femorite (F) c. 1/2 acropodite length in situ, upright, becoming much thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, but not spine-like, spear or flame-shaped; second femoral process (fp1) present, arising close to solenomere base, curved, pointed, banana-shaped; prolongation of femorite apex (prof) absent; solenomere (S) long, forming >1 loop/circle, generally more slender than femorite, thick at base, thinner at tip; solenomere tip pointed, with no serrations; solenomere process (sp1) near solenomere tip, small, pointed, upright, slender; second solenomere process (sp2) near solenomere base, prominent, not pointed;, serrated and saw-like (Figures 31C–F).

Female

Similar to male but broader (midbody width c. 3 mm) (WAM T96075).

DISTRIBUTION

All specimens were collected from the Marvel Loch area by hand from under rocks, logs and leaf litter (Figure 40).

ETYMOLOGY

The species is named for the prominent serrations at the base of the solenomere on the gonopod (Latin, *serratus*, toothed like a saw).

Antichiropus simpulus **sp. nov.**

Figures 32, 40

http://www.zoobank.org/urn:lsid:zoobank.org:act:6F54FB79-EA7B-42E9-96DB-63169C040513

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , N of Mt Dean, 32°13′19″S, 123°38′41″E, 15 April 2001, under limestone rocks, open flat, A. Baynes, L.M. Hatcher, M.R. Norton and R.E. Webb (WAM T112931).

Paratypes

Australia: ***Western Australia*:** 6 , 1 , collected with holotype (WAM T72602). 1 , collected with holotype (WAM T112930).

Other material

Australia: ***Western Australia*:** 4 , 3 (specimens in pieces), Cardanumbi, 32°17′S, 125°, 36′E, 1 June 1914, W.B. Alexander (WAM T349, old number 14/1010); 6 , Kangawarie Clearing, c. 50 km NW of Israelite Bay, 33°13′36″S, 123°38′16″E, 7 August 2005, under limestone near sunken tank, A.F. Longbottom (WAM T66524, T66525, T112619); 2 , Caiguna Blowhole, 5 km W of Caiguna, 32°16′S, 125°26′E, 29 August 1999, crawling down rim of blowhole, A.F. Longbottom (WAM T71975) 1 , 4 , 1 juvenile, Cocklebiddy Cave (6N–48), doline, 31°57′59″S, 125°55′01″E, 16 November 2002, under limestone rocks, M.S. Harvey and M.E. Blosfelds (WAM T71976, T71977, T71978); 1 , Twilight Cove, 32°16′S, 126°02′E, 26 September 1970, L.E. Koch and A.M. Douglas (WAM T71979); 1 remains, possibly , Noondoonia Station, near homestead, 32°19′S, 123°43′E, 9 September 1999, under granite flake, A.F. Longbottom (WAM T72597); 1 , 1 juvenile, Noondoonia Station, 250 m SE of homestead, 32°19′S, 123°43′E, 13 September 1999, in litter, A.F. Longbottom (WAM T72598); 2 , 1 , N of Mt Dean, 32°13′19″S, 123°38′41″E, 15 April 2001, under limestone rocks, open flat, A. Baynes, L.M. Hatcher, M.R. Norton and R.E. Webb (WAM T72599, T62601, T112930); 1 , N of Mt Dean, 32°13′15″S, 123°38′46″E, 13 April 2001, under limestone rock, L.M. Hatcher and A. Baynes (WAM T72600); 1 , 3 , 3 juveniles, SE of Cocklebiddy, on track to Eyre Bird Observatory, 32°03′50″S, 126°16′52″E, 31 January 2009, on ground, M.L. Moir and K.E.C. Brennan (WAM T109762).

FIGURE 32 *Antichiropus simpulus* sp. nov.: A and C holotype male (WAM T112931) habitus: A, lateral view; C, dorsal view; B, male (WAM T72599) left gonopod, solenomere tip; D–G paratype male (WAM T112930) left gonopod: D posterior view; E, anterior view; F, medial view; G, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF prefemur; S, solenomere; serr, serrations; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 0.2 mm; C = 2 mm; D–G = 0.5 mm.

DIAGNOSIS

Gonopod: *Antichiropus simpulus* has a relatively large spoon-like tip to the gonopod, a feature shared with *A. mammillifer*, *A. cavernus* and *A. rex* but it may be distinguished by the shapes of the main femoral process and the second femoral process, the former being noticeably serrated (Figures 32B, D–G).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with distinct waist, prozonite and metazonite of similar width. Colour dark brown, almost black (Figure 32A); leg colour coloration as for body. No paranota on posterior rings (Figure 32C). Some sternites, except ring 5, with protuberances bearing long setae, sternite of ring 5 with obvious processes/tubercles projecting anteriorly, sternal lamella relatively narrow, with rounded edge. Anterior spiracles at midbody flat, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks partially obscuring cardines, when viewed face-on, maximum width c. 3.9 x the distance between antennal sockets; sockets separated by c. 1.6 x width of socket. Antennae of moderate length, reaching to ring 2, not obviously clavate, antennomeres 5 and 6 only slightly wider than proximal ones and relatively slender. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker, and of similar length to femorite, with noticeable ridge on anterior surface; Prefemur (PF) somewhat shorter than femorite, appearing to hug femorite base; femorite (F) c. 1/2 acropodite length in situ, upright, of similar thickness along length; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, serrated on one edge; second femoral process (fp1) present, arising close solenomere base, long, upright, pointed; prolongation of femorite apex (prof) absent; solenomere (S) long, forming >1 loop/circle, generally as thick as femorite, thinnest at base, then thickening; solenomere tip flattened, with no serrations, distinctive spoon-shaped apex; solenomere process (sp1) at solenomere tip, tiny, ridge-like (Figures 32B, D–G).

Female

Similar to male but slightly larger and noticeably

broader, midbody width c. 3 mm (WAM T73602).

DISTRIBUTION

This species is relatively widespread as it has been collected from a number of localities ranging from Kangawarie clearing, about 50 km north-west of Israelite Bay in the west to Cocklebiddy Cave on the Nullarbor in the east, a distance of c. 200 km (Figure 40).

ETYMOLOGY

The species name refers to the spoon-shaped tip to the male gonopod (Latin, noun, *simpulum,* small ladle).

Antichiropus succedaneus **sp. nov.**

Figures 33, 40

http://www.zoobank.org/urn:lsid:zoobank.org:act:BE39AD86-B15D-4811-A201-82E18CADF93F

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , King Rock, 29.4 km NE of Hyden, 32°18′46″S, 119°09′52″E, 18 July 2006, J.M. Waldock and R. Engel (WAM T108898).

FIGURE 33 *Antichiropus succedaneus* sp. nov.: holotype male (WAM T108898) habitus: A, lateral view; B, dorsal view; C–F, left gonopod: C, posterior view; D, anterior view; E, medial view; F, lateral view. Abbreviations: C, coxa; F, femorite; MFP, main femoral process; PF prefemur; prof, prolongation of femorite; S, solenomere; sp1, solenomere process 1. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

Paratype

Australia: ***Western Australia*:** 1 , collected with holotype (WAM T112946).

Other material

None.

DIAGNOSIS

Gonopod: *Antichiropus succedaneus* is very similar to *A. inflatus* (Figures 21C–F) because each has a long solenomere process that forms a pincer shape with the solenomere tip, and a bulbous main femoral process arising from a relatively long slender femorite. *A. succedaneus* differs from *A. inflatus*, however, by its more curved femorite (anterior view), a less bulbous and longer main femoral process and a solenomere tip that is much less spatulate (Figures 33C–F).

DESCRIPTION

Male holotype

Body c. 27 mm long; midbody ring c. 2.5 mm wide, with distinct beaded waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 33A); legs noticeably paler than body. Paranota on posterior rings small (Figure 33B). Sternites without obvious processes/tubercles, sternal lamella: broad, helmet-shaped. Anterior spiracles at midbody protuberant, folded. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face narrow, cardines and stipites clearly visible when animal is viewed face-on, maximum width c. 3.4 x the distance between antennal sockets; sockets separated by c. 2 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate and antennomeres relatively robust. Collum 1 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) more robust, thicker and shorter than femorite, with slight ridge on anterior surface; prefemur (PF) considerably shorter than femorite, ovoid, appearing to hug femorite base; femorite (F) c. 2/3 of acropodite length in situ, slightly curved when viewed anteriorly or upright, and of similar thickness along length; main femoral process (MFP) stout and very long, at least 1/2 solenomere length, pointed, but not spine-like, bulbous; second femoral process (fp1) absent; prolongation of femorite apex (prof) present, small, triangular and pointed; solenomere (S) relatively short, forming circle, generally more slender than femorite, thick at base, becoming thinner midlength, thickening again at tip; solenomere tip with single, broadly flattened end and no serrations; solenomere process (sp1) near solenomere tip, prominent and extending beyond solenomere tip, pointed, upright, slender (Figures 33C–F).

DISTRIBUTION

This species is known from only three specimens found on King Rock, a granite outcrop c. 30 km north-east of Hyden (Figure 40).

ETYMOLOGY

The species name refers to the fact that this was the last species to be identified for this paper (Latin, *succedaneus,* following after).

***Antichiropus westi* sp. nov.**

Figures 34, 40

http://www.zoobank.org/urn:lsid:zoobank.org:act:BC38A35C-876D-4ED5-8528-AA15036E6D31

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** , Mt Gibson Station, site 6, 29°43′35″S, 117°18′28″E, 20–31 August 2001, dry pitfall traps, bowgada/*Melaleuca* shrubland on deep red sands, Biological Survey (WAM T78736).

Paratypes

Australia: ***Western Australia*:** 1 , Mt Gibson iron ore mine, Iron Hill, 10 May 2005, under rock, M.S. Harvey and S. Thompson (WAM T65520); 2 , 1 , Mt Gibson Station, site 7, 29°42′09″S, 117°18′23″E, 20–31 August 2001, dry pitfall traps, mixed bowgada/*Allocasuarina* on yellow gravelly sand, Biological Survey (WAM T65522); 1 , collected with holotype (WAM T65523).

Other material

Australia: ***Western Australia*:** 1 , Mt Gibson iron ore mine, Banded Ironstone Ridge, Mt Gibson east facing (site 10), 29°35′38″S, 117°11′16″E, 30 April–11 May 2005, wet pitfall traps, M.S. Harvey and S.Thompson (WAM T65492); 1 , 1 , Mt Gibson iron ore mine, Banded Ironstone Ridge, Extension Hill east facing (site MTGIB2), 29°34′27″S, 117°09′39″E, 30 April–11 May 2005, wet pitfall traps, M.S. Harvey and S. Thompson (WAM T65493);1 , Mt Gibson iron ore mine, Ironstone Slope, Iron Hill west facing, 29°36′13″S, 117°10′17″E, 30 April–11 May 2005, wet pitfall traps, M.S. Harvey and S. Thompson (WAM T65494); 2 , Mt Gibson iron ore mine, Banded Ironstone Ridge, Extension Hill west facing, 29°34′33″S, 117°09′38″E, 30 April–11 May 2005, wet pitfall traps, M.S. Harvey and S. Thompson (WAM T65495); 1 , Mt Gibson Station at 29°47′00″S, 117°23′18″E, 24 August 2001, york gum woodland on yellow sandy loam, A. Baynes (WAM T65521); 2 , Mt Gibson iron ore mine, Banded Ironstone Ridge, Extension Hill west facing, 29°34′33″S, 117°09′38″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65531); 1 , Mt Gibson iron ore mine, woodlands 1 (A) impact site, 29°34′09″S, 117°10′36″E, 30 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65533); 1 , Mt Gibson iron ore mine, Banded Ironstone Range, Iron Hill west facing, 29°36′10″S, 117°10′20″E, 30 April–11 May 2005, wet pitfall traps, S. Thompson (WAM T65535); 2 , Mt Gibson iron ore mine, Ironstone Slopes, Iron Hill east facing, 29°36′08″S, 117°10′27″E, 1–11 June 2005, wet

FIGURE 34 *Antichiropus westi* sp. nov.: male A-B habitus: A (WAM T65495) lateral view; B (WAM T65520), dorsal view; C–F, paratype male left gonopod (WAM T65520): C, posterior view; D, anterior view; E, anteromedial view; F, lateral view. Abbreviations: C, coxa; F, femorite; fp1, second femoral process; MFP, main femoral process; PF; S, solenomere; sp1 and sp2, solenomere processes 1 and 2. Scale bars: A = 2 mm; B = 1 mm; C–F = 0.5 mm.

pitfall traps, S. Thompson (WAM T65536); 2 , Mt Gibson iron ore mine, Ironstone Slopes, Extension Hill, east facing, 29°34′32″S, 117°09′49″E, 1–11 June 2005, wet pitfall traps, S. Thompson (WAM T65537); 2 , Mt Gibson iron ore mine, Ironstone Slopes, Mt Gibson east facing, 29°34′38″S, 117°09′35″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65539); 1 , Mt Gibson iron ore mine, Ironstone Slopes, Mt Gibson west facing, 29°35′36″S, 117°10′55″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65547); 1 , Mt Gibson iron ore mine, Ironstone Slopes, Extension Hill, west facing, 29°34′38″S, 117°09′35″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65548); 2 , 1 , Mt Gibson iron ore mine, Ironstone Slopes, Iron Hill east facing, 29°36′08″S, 117°10′27″E, 31 May–11 June 2005, wet pitfall traps, S. Thompson (WAM T65549); 1 , 1 , Mt Manning area, site CR3, 30°27′36.8″S, 120°00′09.5″E, 25 June 2008, open *Casuarina* woodland with mixed shrubs, J. Francesconi et al. (WAM T92078); 2 , Mt Manning area, site CM5, 30°21′18.1″S, 119°53′45.2″E, 21 June 2008, open tall eucalypt woodland with *Eremophila* shrubs, J. Francesconi et al. (WAM T92094); 1 , Mt Jackson, 106.5 km N of Southern Cross, 30°16′10″S, 119°14′09″E, 12 October 2008, soil and leaf litter, R. Teale and Z. Hamilton (WAM T93837); 1 , 1 , 2 juveniles, NE of Southern Cross, Helena and Aurora Ranges (Aurora Project), 30°21′28″S, 119°41′58″E, 9 May 2009, M. Bamford (WAM T98520); 1 , Windarling, 92.0 km NNW of Koolyanobbing, 30°00′35.64″S, 119°18′22.03″E, 12 August 2009, leaf litter, R. Teale (WAM T99048); 1 , Deception, 109.5 km N of Koolyanobbing, 29°51′00″S, 119°16′42″E, 29/06/2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104613);′1 , Deception, 108.8 km N of Koolyanobbing, 29°51′30″S, 119°16′12″E, 30 June 2010,

leaf litter, Z. Hamilton and J. Cairnes (WAM T104620); 1 , Deception, 108.8 km N of Koolyanobbing, 29°51′30″S, 119°16′12″E, 30 June 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104621); 5 , Deception, 109.5 km N of Koolyanobbing, 29°50′57″S, 119°16′59″E, 30 June 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104627–T104630, T104632); 4 , Deception, 102.5 km N of Koolyanobbing, 29°55′10″S, 119°15′26″E, 1 July 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104634, T104635, T104637, T104638); 1 , Deception, 89.6 km N of Koolyanobbing, 30°02′07″S, 119°16′29″E, 3 July 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104653); 2 , Windarling, 92.5 km N of Koolyanobbing, 30°00′44″S, 119°15′46″E, 7 July 2010, leaf litter, Z. Hamilton and J. Cairnes (WAM T104655, T104656); 1 , 1 , 2 juveniles, 190 km NW of Kalgoorlie, Lake Giles, site 09 - Snark, 29°49′08.95″S, 119°56′16.75″E, 15 June 2011, M.K. Curran and S.R. Bennett (WAM T114007); 1 , Marda, 114 km N of Southern Cross, 30°11′53.22″S, 119°15′15.19″E, 22–23 September 2011, dry pitfall trap, north-facing slope, M. Peterson (WAM T116732); 3 , 1 , 6 juveniles, Mummaloo, c. 75 km NE of Wubin, 29°39′33.10″S, 117°13′51.90″E, 1 May 2012, hand foraging, under *Eucalyptus* tree, M.K. Curran and G.B. Pearson (WAM T125749); 2 , 1 , c. 7 km SW of Yandhanoo Hill, Bonneydoon, 29°53′00.00″S, 117°12′43.00″E, 15 August 2013, hand foraging, M. Bamford (WAM T128666); 1 , 1 juvenile, Bungalbin Hill, 50 km Nof Koolyanobbing, 30°23′45.57″S, 119°39′18.31″E, 3–11 April 2013, leaf litter, S. White, A. Heidrich, A. Nowicki, J. Vos and F. Bokhari (WAM T130656).

DIAGNOSIS

Gonopod: the species *Antichiropus howardi* (Figures 19C–F), *A. incomptus* (Figures 20C–F) and *A. westi* each have a simple gonopod structure, but *A. westi* has two processes on the femorite whereas the other two species each have only the main femoral process on the femorite (Figures 34C–F).

DESCRIPTION

Male holotype

Body c. 25 mm long; midbody ring c. 2.5 mm wide, with less pronounced waist, prozonite and metazonite of similar width. Colour dark brown overall (Figure 34A); leg colour as for body. No paranota on posterior rings (Figure 34B). Sternites without obvious processes/tubercles, sternal lamella broad, helmet-shaped. Anterior spiracles at midbody flat, erect. Head smooth, without noticeable sculpturing; frons smooth, with some setae; face broad, cheeks at least partially obscuring cardines, when viewed face-on, maximum width c. 3.7 x the distance between antennal sockets; sockets separated by c. 1.7 x width of socket. Antennae of moderate length, reaching to ring 2, distinctly clavate, antennomeres relatively robust. Collum 0.6 x as long as head (in lateral view). Gonopod of medium length, reaching posterior edge of ring 5; coxa (C) thicker, of similar length to femorite, with slight ridge on anterior surface; prefemur (PF) somewhat shorter than femorite; femorite (F) c. 1/2 acropodite length in situ, becoming thicker towards apex; main femoral process (MFP) long (to c. 1/4 solenomere length), pointed, hatchet-shaped; second femoral process (fp1) present, arising close to solenomere base, upright, pointed, banana-shaped; prolongation of femorite apex (prof) absent; solenomere (S) relatively short, forming circle, generally more slender than femorite; solenomere tip flattened, with no serrations, broadly arrow-shaped: solenomere process (sp1) closer to tip than base, small, pointed, upright (Figures 34C–F).

Female

Similar to the male in length but generally broader, up to 3 mm wide dorsally. The females show the same colour variation as the males with dark brown forms (WAM T114007) and those with a broad pale dorsal stripe (WAM T65493). It appears that males and females of the same colour form occur together.

DISTRIBUTION

This species has been collected from a number of localities in wet and dry pitfall traps and by hand from leaf litter at Mt Gibson station, Mt Jackson and Deception (100 km north of Koolyanobbing) (Figure 40) which makes it a relatively wide ranging species.

REMARKS

Some *A. westi* specimens with no discernible differences in gonopod structure may show colour variation: some are uniformly dark brown in colour, while others have a noticeable lighter brown longitudinal dorsal stripe.

In addition, a number of specimens have gonopods that are similar in overall configuration but show small variations. For example, some specimens carry either a minute two-pronged process or a tiny triangular process at the distal end of the femorite, which could be considered a tiny prolongation of the femur: others show slight variation in the shape of the second femoral process. The species is relatively widespread but as yet, no pattern of variation due to geographical location has been discerned. Up to this point, species have been easily separable by gross differences in the structure of their gonopods. Consequently, despite these perceptible variations in structure, all specimens with gonopods of overall similar structure to *A. westi* have been included in this species. Further morphological, geographical and genetic studies are required to resolve the relative importance of these variations, as has been done for the marri millipede, *A. variabilis,* by Wojcieszek and Simmons (2009, 2011a, 2011b, 2013).

ETYMOLOGY

This species is named in honour of Paul West of Cliffs Natural Resources whose support enabled this project to be undertaken.

DISCUSSION

As litter dwellers, paradoxosomatids are generally susceptible to desiccation, but are able to survive in small localized areas of suitable microclimate (Sierwald and Bond 2007) even in semi-arid regions such as the Great Western Woodlands (Watson et al. 2008). Paradoxosomatid species are also vulnerable to disturbances in their habitat, such as land clearing and fragmentation (Car 2010) and are known to have poor dispersal ability (Harvey 2002). The Great Western Woodlands area is relatively undisturbed by human activity, due partly to an historical turn of events, and partly to unreliable and low rainfall, making agriculture difficult (Yates et al. 2000; Judd et al. 2008; Prober et al. 2012). This lack of disturbance in an area with abundant suitable microclimates has contributed to the diversity of the *Antichiropus* fauna.

In keeping with most paradoxosomatid species, it seems that nearly all of the *Antichiropus* species in the Great Western Woodlands may be characterised as short-range endemics (Harvey 2002). Some species described here, such as *A. axicius, A. cincinnus*, *A. giganteus* and *A. inflatus* are known only from single specimens (Figures 18, 36, 38). This rarity could be due to the difficulty of collecting specimens when they are active, but it is likely that they have genuinely restricted ranges which do not overlap at small ecological scales (Harvey et al. 2000). Several species, such as *A. buchanorum* and *A. saxatilis* were found in very localized areas (Figures 36, 39), associated only with granite outcrops, which seem to act as 'islands' of suitable habitat for millipedes (C. Car and J. Waldock, personal observations). Even well collected species such as *A. baudini* and *A. framenaui* tend to have very limited distributions (Figures 35, 37). It is also common for millipede species' distributions to form mosaic patterns in the landscape (Mesibov 2003) and those of the Great Western Woodlands area seem to follow this general pattern, for example, *A. exclamatus* (Figure 37).

The north-western region of the woodlands, the Mt Gibson area, appears to be particularly rich in *Antichiropus* species: five sympatric species occur there, namely, *A. alastairi, A. alatus, A. axicius*, *A. sagittulus* and *A. westi* (Figures 35, 36, 39, 40). Collecting effort was, however, much more intense in this particular area compared with others in the Great Western Woodlands. The results at Mt Gibson suggest that other areas of the Great Western Woodlands may yield more species and show similar species richness to Mt Gibson if targeted surveys were conducted on the infrequent occasions when millipedes are active above ground, i.e. after good rain (Car 2009).

Several of the species in the area cannot be classed as short-range endemics as they have fairly broad ranges. These include *A. exclamatus, A. laticlavius, A. simpulus* and *A. westi* (Figures 37, 39, 40). The reasons for their wider distribution patterns are unknown, although there is some slight morphological and gonopodal variation apparent in at least one of these species, *A. westi*. Genetic studies may provide the answers to questions regarding these species' ranges, along the lines of recent research into the marri millipede *A. variabilis* (Wojcieszek and Simmons 2009, 2011a, 2011b, 2013).

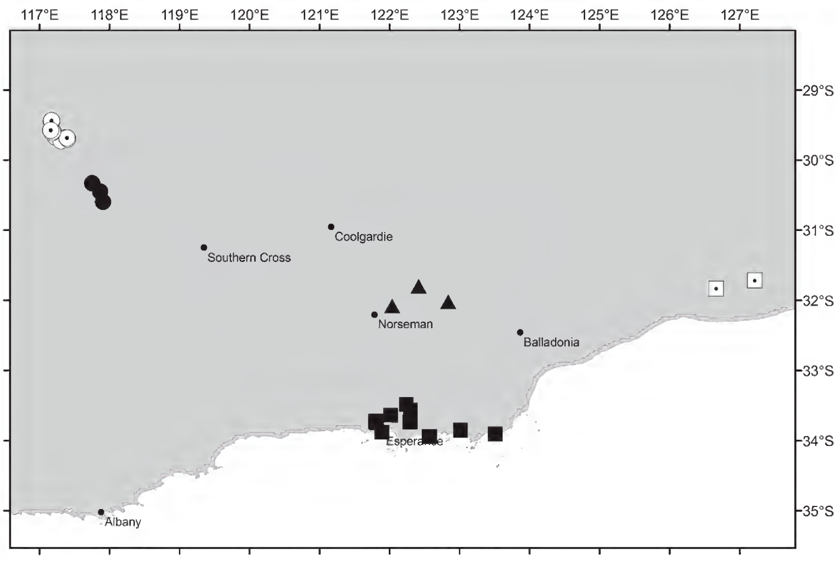

FIGURE 35 Recorded distributions of *Antichiropus alastairi* (filled circles), *A. alatus* (dotted circles), *A. anconus* (filled triangles), *A. baudini* (filled squares) and *A. cavernus* (dotted squares).

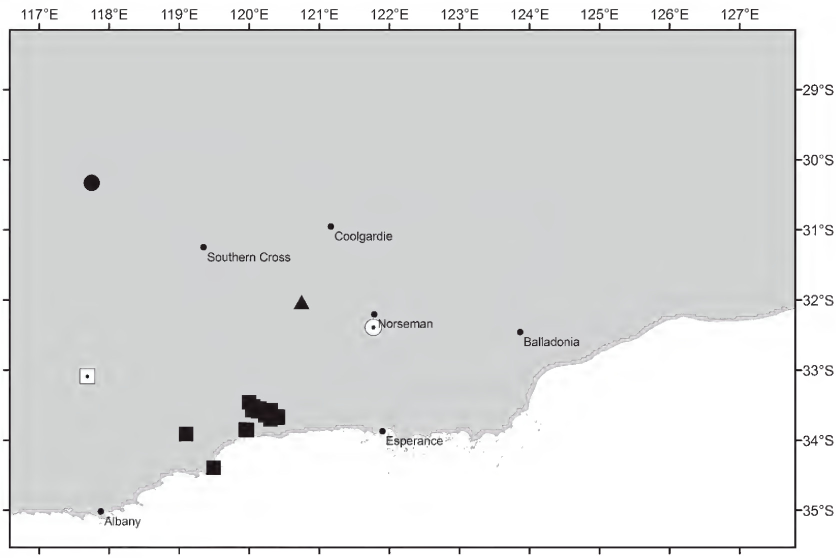

FIGURE 36 Recorded distributions of *Antichiropus axicius* (filled circle), *A. buchanorum* (dotted circle), *A. cincinnus* (filled triangle), *A. cuspis* (filled squares) and *A. digitatus* (dotted square).

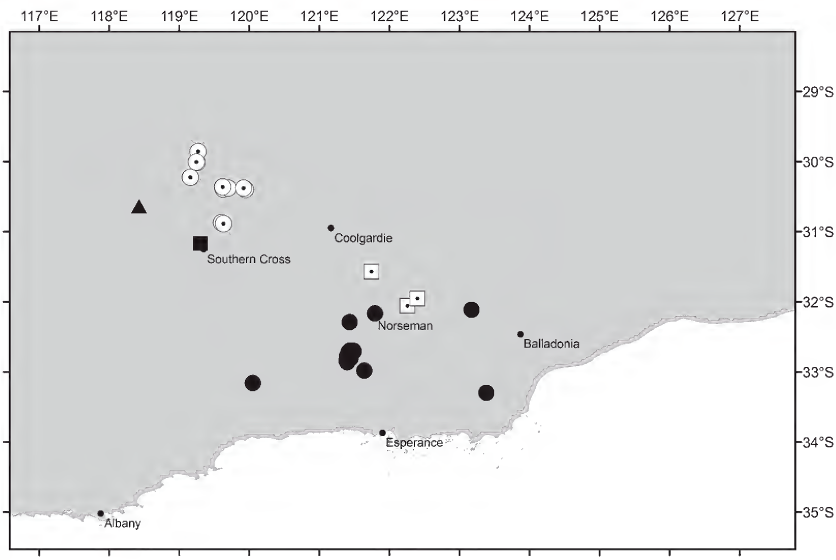

FIGURE 37 Recorded distributions of *Antichiropus exclamatus* (filled circles), *A. framenaui* (dotted circles), *A. giganteus* (filled triangle), *A. howardi* (filled square) and *A. incomptus* (dotted squares).

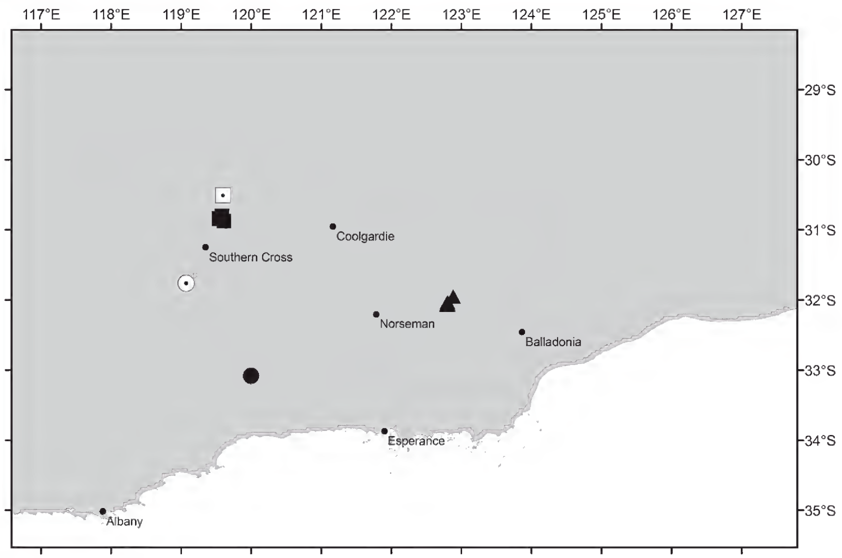

FIGURE 38 Recorded distributions of *Antichiropus equinus* (filled circle), *A. inflatus* (dotted circle), *A. inopinatus* (filled triangles), *A. kealleyi* (filled squares) and *A. lacustrinus* (dotted square).

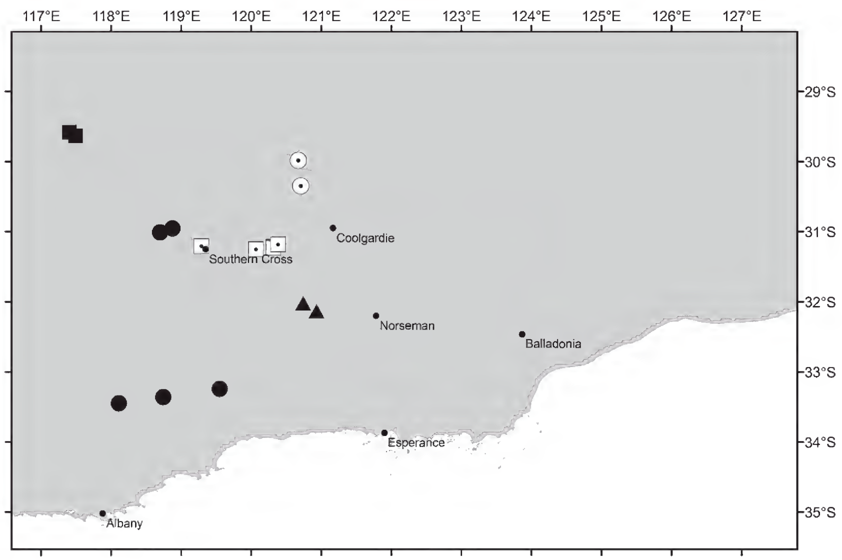

FIGURE 39 Recorded distributions of *Antichiropus laticlavius* (filled circles), *A. nadineae* (dotted circles), *A. paracalothamnus* (filled triangles), *A. sagittulus* (filled squares) and *A. saxatilis* (dotted squares).

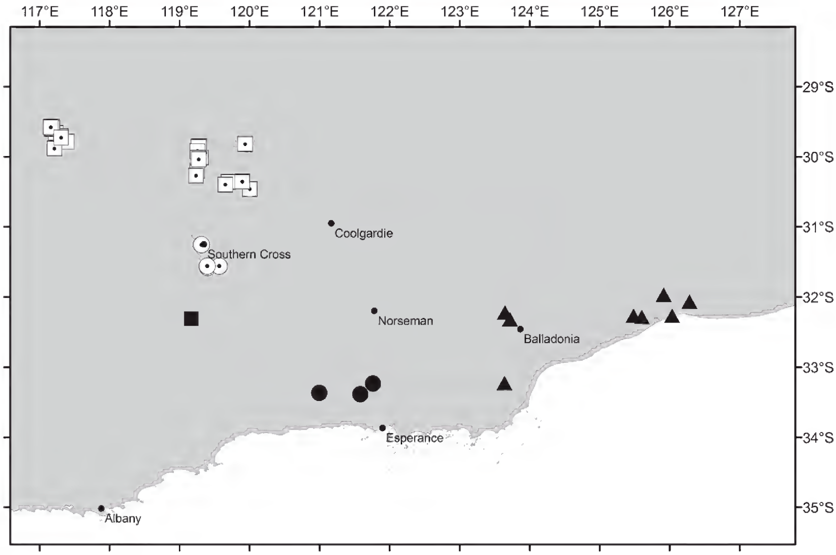

FIGURE 36 Recorded distributions of *Antichiropus rex* (filled circles), *A. serratus* (dotted circles), *A. simpulus* (filled triangles), *A. succedaneus* (filled square) and *A. westi* (dotted squares).

ACKNOWLEDGEMENTS

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SHORT COMMUNICATION

An anomalous cluster of Irukandji jelly stings (Cnidaria: Cubozoa: Carybdeida) at Ningaloo Reef

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KEYWORDS: Irukandji syndrome, envenomation, Western Australia, Indian Ocean, *Carukia*, *Malo*, *Keesingia*, Carukiidae

INTRODUCTION

An unusually large number of cases of Irukandji syndrome were reported in the northern regions of Ningaloo Marine Park (north of Coral Bay) and into Exmouth Gulf in the period March to June 2013. Seven confirmed sightings of three species of Irukandji jellies were also made during this event (Figure 1, Table 1). The purpose of this communication is to document this event and to provide preliminary information on the ecological context and medical implications.

Irukandji is the common name for numerous types of cubozoan jellies, and for the systemic illness caused by their stings (Williamson et al. 1996; Gershwin et al. 2013). The initial sting is typically mild, but after a delay of some 5–40 minutes, the syndrome onsets with a number of debilitating symptoms including severe lower back pain, nausea and vomiting, difficulty breathing, cramps and spasms, a feeling of impending doom; some cases also include life threatening hypertension.

Two species of Irukandji are currently known from Western Australia, both from the Broome region (Gershwin 2005). Seasonal clusters of stings have occurred in the Broome region for many decades, typically reported from inside Roebuck Bay through December each year, and then from the more exposed Cable Beach from February to June (Macrokanis et al. 2004; Gershwin et al. 2013).

The earliest cases of Irukandji syndrome reported in Australia were from Onslow in 1927 (Stenning 1928), long before the syndrome was named. Ningaloo Reef, however, typically has few or no sting reports each year. It was therefore unexpected when 23 people were hospitalised with Irukandji syndrome from this region in April–June 2013. A comprehensive study on the drivers and implications of high latitude stings is warranted to determine if this novel event is likely to recur.

RESULTS AND DISCUSSION

Sting and specimen reports

Twenty three reported hospitalisations due to Irukandji syndrome, along with three videos, three photographs, and one Irukandji specimen were recorded during this event (Table 1). Cases and sightings were reported from near Coral Bay, north into Ningaloo Marine Park and Exmouth Gulf.

Several additional less severe cases also occurred during this time. These had similar symptoms but did not require hospitalisation, while two more stings in August 2013 presented to the hospital in Coral Bay but did not require the standard magnesium treatment (unpublished data, Exmouth Hospital).

Near the height of this event in mid May, two drownings occurred together at Elle's Beach 50 km south of the southernmost reported stings; media highlighted that Irukandji could have been an underlying cause (AAP 2013). The coroner's report issued seven months after the event concluded that the deaths occurred by way of accident and that "there is no evidence to confirm or deny the involvement of Irukandji". Without nematocyst recovery from skin or observation of Irukandji-type symptoms prior to death, the involvement of Irukandji remains undetermined.

A swarm of what appear to be Irukandji jellies was observed at Rowley Shoals on the night of 9 September 2013 (Figure 2). Whether this swarm was in some way associated with the Ningaloo event is unknown.

Species

At least three genera of Irukandji were involved in this event, *Carukia*, *Malo*, and an unnamed genus and species in the family Carukiidae, determined by gross morphology observable in photos and videos. A single specimen was captured, and proved to be a new species

of *Malo*. Both the *Malo* and the new carukiid have been described (Gershwin, 2014).

Ecological context

The ecological basis for this event has not yet been identified. Gelatinous zooplankton were prolific in 2013 (personal communication, Ben Fitzpatrick, dive tour operator with more than 15 years marine research experience at Ningaloo). In Queensland, the gelatinous pelagic community has been long associated with increased numbers of Irukandji, although the exact relationship has yet to be elucidated (Barnes 1964; Gershwin et al. 2013).

Climate conditions may prove informative. The summer months leading up to the bloom event were warmer overall than other years this century (Figure 3), and a substantial sea surface temperature (SST) spike occurred in February 2013 preceding the bloom event (Figure 4). These warmer conditions offer a number of hypotheses: an explosion in medusa production, a rapid increase in growth rate of already metamorphosed individuals, an increase over a threshold in toxin virulence, or a combination of the above. Photographic evidence (Table 1) and late summer activity suggest that *Malo* was the primary species; although the life cycle of *Malo* remains unknown, its size suggests that it is likely to be longer lived than *Carukia* (see Gershwin et al. 2013). Similarly, while nothing is known about the thermal ecology, growth rate, or toxin ontogeny of *Malo*, a reasonable beginning hypothesis is that it behaves like other medusae, i.e. that reproduction and growth are stimulated by an increase in temperature, and that virulence increases with growth (reviewed in Gershwin et al. 2013). Testing of these hypotheses is imperative.

Two other unusual high latitude clusters have occurred in Australia during or following heat waves: one at Fraser Island, Queensland in December 2012 and January 2013 (Walker 2013), and the other in Botany Bay, New South Wales in the 1930s (Cleland and Southcott 1965). The implications of this phenomenon in the context of planetary warming projections should be considered a high priority for further research.

Moreover, the majority of Ningaloo stings occurred in April and May in clusters coinciding with periods of southerly winds. Preliminary assessment of the environmental criteria established by CSIRO for forecasting Queensland Irukandji, indicate that favourable conditions coincided with the Ningaloo event (Gershwin et al. 2014). This suggests that with further study the occurrence of such events may become predictable.

Medical notes

Sting characteristics throughout the event fell into two fairly distinct categories: those with the 'normal' Irukandji presentation, and several with more severe life threatening symptoms (unpublished data, Exmouth Hospital). Of the more severe, two patients had near cardiac arrest, while a third had an anaphylaxis-like presentation. While Irukandji syndrome is often attributed to anaphylaxis in developing countries, the two responses are quite distinct. Anaphylaxis is an immune-mediated personal problem that causes difficulty breathing via mouth and/or throat swelling, while Irukandji syndrome is a public health problem that causes difficulty breathing via chest constriction or pain. However, the Ningaloo case was sufficiently convincing to cause the treating physician to run a diagnostic test for mast cell tryptase, which proved normal. An Irukandji sting in November 2012 also presented as anaphylaxis-like with a normal mast cell tryptase test; in this case, the pulse was 146 and the patient nearly arrested, but settled with administration of magnesium sulphate. The significance of the similarity of these

FIGURE 1 An Irukandji in the genus *Malo* at Ningaloo Reef, 13 July 2013; no stings were reported this day. This evidence of an Irukandji in the swimming area demonstrates the need for urgent research into prediction and management. (Image courtesy Ben Fitzpatrick / Oceanwise Expeditions.)

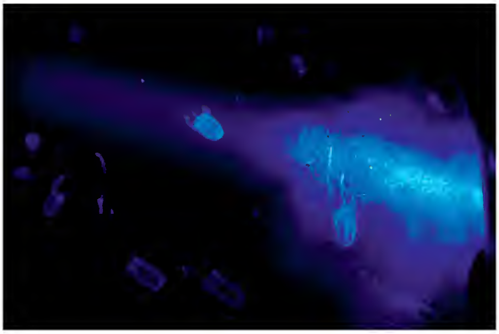

FIGURE 2 Swarm of carybdeid jellies approximately 10cm long at Rowley Shoals on 9 September 2013. No specimens were collected so species identification could not be determined.

TABLE 1 Irukandji stings and specimens from the vicinity of Ningaloo Reef in autumn and winter (April to July) 2013. Although a total of 23 hospitalisations were recorded, not all data could be accessed at the time of this report.

? indicates patient data not currently available.

Date	Patient	Notes
First week of April	9 stings requiring hospitalisation	Details unavailable; reported in media (ABC, 2013)
17 April	--	Video of *Carukia* off Coral Bay (source unknown)
21 April	?	On boat working out of Coral Bay, 70–80 km S of previous cases
27 April	--	New species of Carukiidae photographed near Coral Bay (John Totterdell)
28 April	17 yr f	Turquoise Bay, time 4 pm
10 May	28 yr m	Anaphylactic-like reaction; mast-cell tryptase test negative
16 May	19 yr f	
17 May	53 yr m	
18 May	46 yr f	
20 May	14 yr f	
21/22 May	54 yr f	180/110 BP, hypertensive crisis, required two lots of Nifedipine
19 May	?	
10 June	45 yr f	Diver, back of reef
3 July	--	2 videos of *Malo* from Ningaloo Reef (source unknown)
13 July	--	*Malo* photographed off Tantabiddi (Ben Fitzpatrick)
19 July	--	New species of *Malo* collected by DPaW

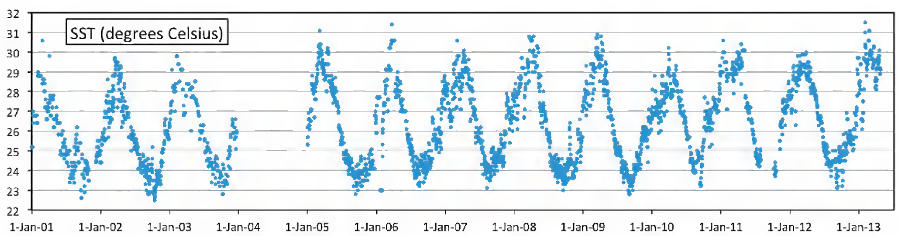

FIGURE 3 Daily sea surface temperature (SST) at the IMOS Ningaloo Reef mooring station, 2001–2013 (data for 2004 were not available at the time of this report). Horizontal axis increments correspond to 1 January of each year. Note the considerable temperature spike in early 2013 preceding the April to July Irukandji bloom event.

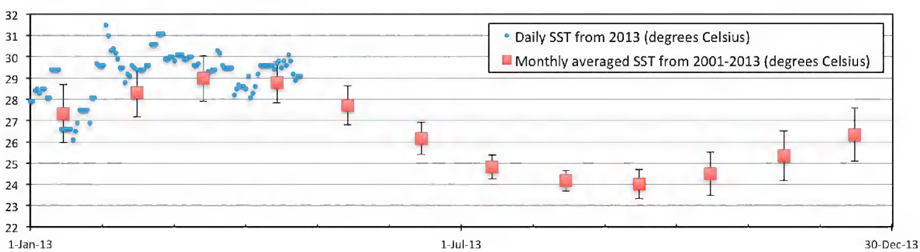

FIGURE 4 Ningaloo Reef mooring station long-term monthly average sea surface temperature (SST) 2001–2012 (red squares), and daily SST for January to April 2013 (blue dots). Bars denote standard deviation. During February 2013 preceding the April to July Irukandji bloom event, the SSTs were more than 2 standard deviations above the mean, in the top 2% of SST values historically observed in this area (assuming that they follow a normal distribution).

cases with anaphylaxis is not yet well understood.

The catecholamine excess of Irukandji syndrome may complicate Takotsubo Syndrome, also known as Stress Cardiomyopathy or Octopus Heart Syndrome, where exertion and subsequent adrenaline release in people over 50 years of age leads to a weakening of the left ventricle. This may be particularly relevant where vigorous swimming and excitement are combined where stings occur in recreational aquatic environments.

Conclusion

It is unclear why so many Irukandji were observed and yet relatively few stings occurred, compared with typical experiences in Queensland and overseas where the jellies are rarely observed.

The local, State, and national response to dealing with this event was challenged by the unexpected nature of it in this region. This raises the issue of planning in other regions that may consider themselves ‘safe’ from such visitations due to their southerly locations. A local alert system for dissemination of high risk conditions and safety information and a system of standardised data collection should be considered, along with establishment of forensic protocols to identify or rule out Irukandji as a cause of morbidity or mortality.

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SHORT COMMUNICATION

A note on the Australian freshwater crocodiles inhabiting Tunnel Creek cave, West Kimberley

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KEYWORDS: *Crocodylus johnstoni*, hot water springs, thermochron iButtons, subterranean habitats

INTRODUCTION

Tunnel Creek National Park, located 390 km east of Broome in the Kimberley region of Western Australia, is one of region's top tourist attractions. The 91 ha national park is positioned within the Napier Range which is composed of limestone, remnants of a Devonian barrier reef system formed around 350 million years ago (Goudie et al. 1990). The park contains a limestone cave system ~750 m in length (cave entrance at 51K 727683 8051871) (Figure 1). It is considered to be one of the oldest cave systems in Western Australia and also a nationally important wetland (Environment Australia 2001). The cave also has historical value as the Aboriginal freedom fighter Jandamarra, a member of the Bunuba group of the area, evaded the police and others for nearly three years using it as a hideout, until he was shot in April 1897 at the cave entrance (Pedersen and Woorunmurra 1995).

The cave is up to 20 m high and up to 20 m wide and contains permanent pools of freshwater throughout the year. Tunnel Creek generally flows during 4–5 months of the year (December to April), during which it is connected to a permanent, large freshwater pool located, ~15 m outside the southern entrance of the cave (Figures 1, 2A). Nearly halfway in, the roof of the cave has collapsed allowing sunlight to reach the banks of the cave in a ~30 m section. Other than this, sunlight does not penetrate the remainder of the cave, beyond the entrances. Two springs with warmer water, possibly created as a result of a perched water table passing through heated rocks outside the cave, flows into the cave creating ~1 m and ~2 m high waterfalls (Figure 1). Water within these two pools is warmer than the other pools within the cave.

While no detailed studies on the herpetofauna of the area have yet taken place, anecdotal information states the occasional presence of Australian freshwater crocodiles (*Crocodylus johnstoni*) inside the cave (Gueho 2003; Laurie 2010). Confirmed records of crocodilians inhabiting large caves are very rare and limited to a population each of the dwarf crocodile (*Osteolaemus* sp.) and the Nile crocodile (*C. niloticus*) (Handwerk 2003; IRD 2012). Hence in this short note, we provide more robust observational records of the population of *C. johnstoni* inhabiting the Tunnel Creek cave and discuss likely reasons for their occupation of the cave.

METHODS

During ongoing surveys by the Department of Parks and Wildlife of Western Australia for freshwater crocodiles in the West Kimberley region, Tunnel Creek cave was visited on eight occasions between May 2011 and September 2013 (Table 1). Spotlighting was conducted using headlamps and hand-held spotlights inside the cave (during daylight hours) and at the pool outside during night time (18:00–6:00). The outside pool was also searched for crocodiles and their signs more regularly during daytime. Once an eye shine was observed, attempts were made to approach the crocodile and estimate the size. Notes on the location and activity were made. On 9 June 2013, thermochron iButton data loggers [programmed to record temperature and relative humidity (in only those that were above water) at 20 min intervals over 17 hrs] were placed one per pool, ~20 cm underwater near the waterfall inflows at the two warm pools, two other pools inside the cave (cold pools 2 and 4), and the pool outside, while two loggers each were placed ~50 cm above ground level inside the cave (on ledges on the cave wall ~200 m from an entrance) and outside (suspended in air from trees ~50 m away from the two entrances). Those set above ground recorded both temperature and humidity. Additionally the air temperature was measured using a digital thermometer (CEM 4 in 1 Environment Meter DT–8820) outside the southern entrance and at the second warm pool inside the cave during visits (Table 1).

TABLE 1 Observations of crocodiles made within the Tunnel Creek cave. Temperatures refer to those measured using a hand-held thermometer at the outside pool and the second warm pool inside the cave.

Date	Time	Outside air temperature	Inside air temperature	Number of crocodiles	Observations
13 May 2011	11:30	24.7	21.6	2	1. 120–150 cm animal on rocks directly under flowing spring in warm pool 1 2. Eye shine in deep water at a cold pool 2
14 May 2011	19:40	16.9	19.3	2	1. Eye shine at water's edge in warm pool 1 2. Eye shine in deep water at warm pool 2
2 Sep 2011	8:10	24.3	20.1	3	1. 150–180 cm animal at water's edge in cold pool 2 2. Eye shine in deep water at warm pool 1 3. Eye shine in deep water at warm pool 2
16 June 2012	13:20	31.7	21.9	4	1. 150–180 cm at water's edge in warm pool 1 2. 120–150 cm in deep water at warm pool 2 3. Eye shine in deep water at cold pool 4 4. Yearling (37 cm) in shallow cold pool, ~60 m inside of the south entrance
16 June 2012	21:20	18.4	19.7	4	1. 150–180 cm at water's edge in warm pool 1 2. 120–150 cm in deep water at warm pool 2 3. Two eye shines in deep water at cold pool 4
9 June 2013	8:00	27.6	23.4	2	1. 120–150 cm animal on a rock directly under the flowing spring at warm pool 2 2. Eye shine in deep water at cold pool 2
10 June 2013	6:00	22.6	23.0	3	1. 120–150 cm on a sand bank bordering warm pool 2 2. 120–150 cm at water's edge in warm pool 2 3. Eye shine in deep water at cold pool 4
26 Sep 2013	8:00	21.6		2	1. 150–180 cm animal in shallow water directly under flowing springs in warm pool 1 2. Eye shine in deep water at cold pool 1

RESULTS

At least two crocodiles were observed within the cave during each survey with four individuals observed in June 2012 (Table 1). Six of the 11 observations were made at less than 5 m from the animal and all individuals observed closely were noticeably paler in colour relative to those observed at Windjana Gorge, ~30 km north-east, the closest other water body where surveys took place. Six observations were made at warm pool 1 and seven at warm pool 2, compared to nine observations in all other locations inside the cave, indicating a possible preference to warm pools (e.g. Figure 2B). The smallest individual encountered was a 37 cm (total length) hatchling in June 2012, which was estimated to be 7–8 months old. The largest, a 150–180 cm individual, was observed during four of the visits. Apart from one observation of a 120–150 cm crocodile on a sand bank (Figure 2C), all other observations were of animals in water. Numerous tracks were observed on the sand banks within the cave and those that lead to the pool outside (Figure 2D). Despite clear signs of crocodiles moving between the pools inside and outside, no crocodiles were observed in the outside pool during any of the surveys. The two warm springs inside the cave were flowing during all surveys except in September 2011 and September 2013, during the peak dry season. Tracks leading to the bank in the section where the roof has collapsed were observed in September 2013.

Data logger recordings on 9–10 June 2013 showed that the warmer pools maintained a temperature ~0.5° higher than the cold pools inside and were much more stable over the day (Figure 3). Contrastingly, the pool outside was cooler than the pools inside and the temperature gradually dropped through the night till the morning (being ~1° cooler than the warm pools at 13:20 to ~1.5° at 6:20). However it is noteworthy that these differences are small and within the error margins for iButtons. The air temperature inside the cave showed lower variation (4.1°C, ranging from 19.3–23.4°C) during the visits compared to 24.7°C (ranging from 16.9–41.6°C), ~50 m away but outside the cave (Table 1). Recordings from the data loggers show that the air temperature inside the cave remained largely stable for the 17 hour period on 9 June 2013 while the temperature outside dropped over the same time period (Figure 4). The Relative Humidity (RH) outside on the other hand, remained ~20% less than that inside throughout the 17 hr time period (Figure 4).

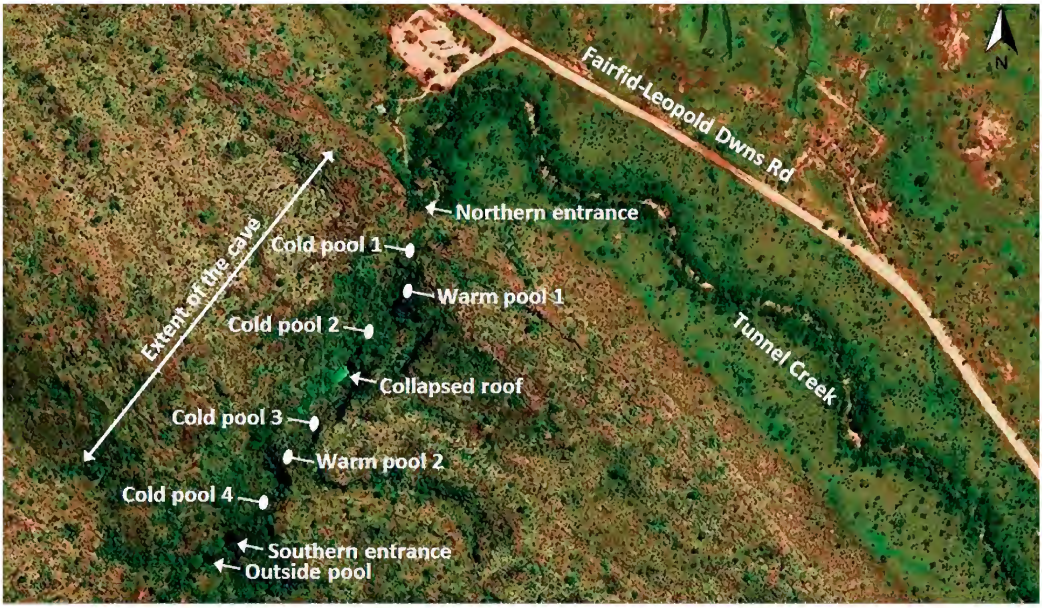

FIGURE 1 Relative positioning of the pools inside and outside the Tunnel Creek cave.

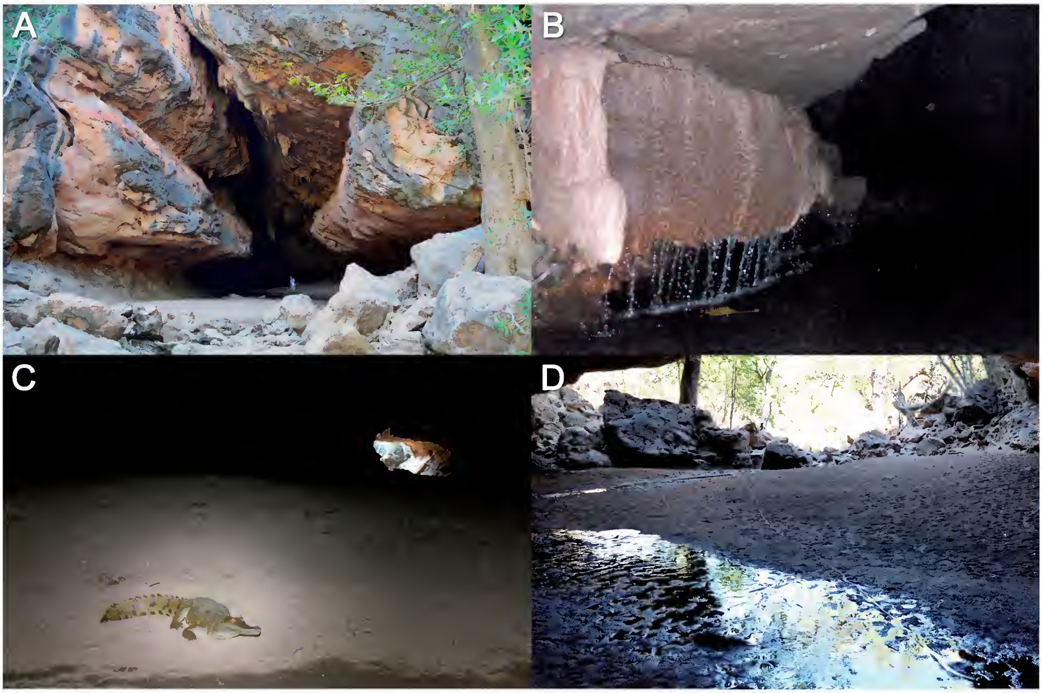

FIGURE 2 A, southern entrance of the Tunnel Creek cave; B, 120–150 cm crocodile directly under the spring at warm pool 2; C, 120–150 cm crocodile on sand bank inside the cave with the southern entrance in the background; D, tracks heading in and out of the cave. Photos A & D: Karen Bettink; B & C: Ruchira Somaweera.

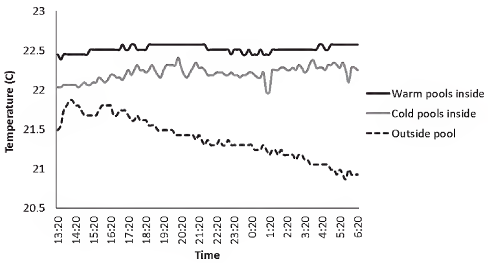

FIGURE 3 Comparison of mean water temperature of the two warm pools and two of the cold pools (2 and 4) inside the cave and the pool outside over 17 hrs on 9–10 June 2013.

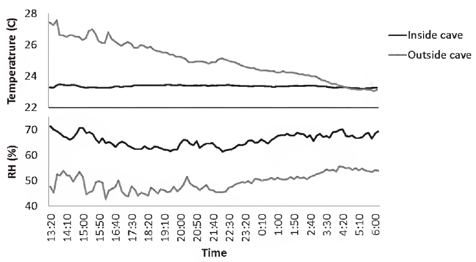

FIGURE 4 Comparison of mean air temperature (upper panel) and mean relative humidity (lower panel) inside and outside the cave over 17 hrs on 9–10 June 2013.

DISCUSSION

Among the few known examples of crocodilians inhabiting large caves is a population of dwarf crocodiles (*Osteolaemus* sp.) in karst caves of Abanda in Gabon (IRD 2012). This unique population is morphologically different, live in complete darkness, and depend on a diet of cave dwelling animals including bats and invertebrates. A population of Nile crocodiles (*C. niloticus*) is known to inhabit the labyrinth of caves beneath Madagascar's Ankarana Nature Reserve (Handwerk 2003). Steubing et al. (2004) found tracks of false gharials (*Tomistoma schlegelii*) entering caves in Bukit Sarang in Sarawak, Malaysia but no direct observations of individuals were made.

Nevertheless, use of smaller subterranean habitats by crocodilians is well documented. Caverns or burrows are often used by smaller crocodilians as hideouts during daytime (e.g. Chinese alligator, *Alligator sinensis*, African dwarf crocodile, *Ostolaemus tetraspis,* smooth-fronted caiman *Paleosuchus trigonatus*: Magnusson and Lima 1991; Brazaitis and Watanabe 2011); as refugia during the periods guarding nests and protecting hatchlings (e.g. mugger crocodile *C. palustris*, American crocodile *C. acutus*: Gupta and Bhardwaj 1995; Wasilewski and Enloe 2006); and also to avoid adverse environmental conditions such as drought and winter (e.g. Nile crocodile *C. niloticus*, American alligator *Alligator mississippiensis*: Cott 1961; Neill 1971). However, these burrows and tunnels are usually dug by the adults of the species, and in most instances are only used seasonally or as a hideout during part of the day.

Crocodylus johnstoni is endemic to mainland northern Australia and is widespread in the Kimberley region (Burbidge 1987), generally inhabiting upstream permanent freshwater habitats, although they may extends into tidal, brackish waters in a few river systems (Webb and Manolis 2010). Despite its wide range and occupation of a variety of aquatic habitats, there are no records of Australian freshwater crocodiles utilising subterranean habitats, other than using smaller caverns to aestivate during the dry season. *Crocodylus johnstoni* are known to seek refuge in subterranean shelters when water bodies dry entirely (Kennett and Christian 1993; Walsh 1989). Recaptures of *C. johnstoni* in the Northern Territory of Australia indicate high site fidelity to specific caverns for aestivation in the dry season. Potential advantages for *C. johnstoni* seeking shelter in caves to aestivate include predator avoidance, improved thermoregulation, and reduced rates of dehydration (Walsh 1989).

The occupation of Tunnel Creek cave by crocodiles may be based on thermal and foraging benefits. Observations show that crocodiles had a clear preference to warmer pools over cold pools. For example, the largest animal (150–180 cm) was always observed at a warm pool. Crocodilians, especially the dominant individuals, often seek the warmer water if available (Grigg and Seebacher 2001). In the dry season of September 2013, when one spring was not flowing, we observed clear signs of crocodiles coming up to the section with the collapsed roof, arguably for basking. However, it is likely that the crocodiles occupying the Tunnel Creek cave are mainly following a thermoconformity pattern where the body temperature equals water temperature (Seebacher and Grigg 1997), as the conditions inside the cave may not support active thermoregulation.

The cave may also provide foraging benefits for the crocodiles. *Crocodylus johnstoni* is an opportunistic predator having a wide breadth in prey items. Eel-tailed catfishes (*Anodontiglanis dahli* and *Neosilurus hyrtlii*), short-finned eels (*Anguilla bicolor*), spangled perch (*Leiopotherapon unicolor*) bony bream (*Nematalosa erebi*) and cherubin (*Macrobrachium rosenbergii*) are abundant in the much smaller pools within the cave (compared to the larger pool outside). Several species of bats (*Macroderma gigas, Vespadelus caurinus, Vespadelus douglasorum, Miniopterus schreibersii,*

Pteropus scapulatus; see McKenzie and Bullen 2012 for additional species), frogs (e.g. *Litoria caerulea*, *L. pallida*) and snakes (e.g. *Lialis olivaceus*, *Boiga irregularis*) were observed within the cave during the surveys and all these groups are known prey items of freshwater crocodiles (Tucker et al. 1996; Webb et al. 1982). Predator avoidance may not be a potential reason for inhabiting the cave as most animals observed were adults or sub-adults, those without a natural predator in the area.

The much paler colouration observed in the crocodiles at Tunnel Creek cave could have mainly been a result of the darker conditions within the cave, as crocodilians in darker environments tends to develop lighter body colours (Richardson et al. 2002; but see Kirshner 1985). However, animals with high growth rates also tend to be paler than their counterparts that are subordinate, probably due to hormonal influence (Richardson et al. 2002; C. Manolis, pers. comm., 2013). It is also possible that the lighter colour was an artefact of agitation/excitement due to us approaching the crocodiles (Kirshner 1985), although we did not observe similar colour changes in other sites where crocodiles were caught by us. The *Osteolaemus sp.* in karst caves of Abanda in Gabon has a lighter and a more orange body colour compared to those outside (IRD 2012), but the *C. niloticus* individuals in the caves at Ankarana Nature Reserve are of normal pigmentation (Wilson 1987).

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Two new species of the beetle genus *Pogonoglossus* from the Pilbara region of north-western Australia (Coleoptera: Carabidae: Physocrotaphini)

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ABSTRACT – Two new species of the carabid genus *Pogonoglossus* Chaudoir are described from the Pilbara region of north-western Australia: *P. frater* sp. nov. and *P. soror* sp. nov. The new species were detected in the course of a survey for subterranean organisms in mining areas and were collected by scraping the inside of drill holes in the ground. Both new species are poorly pigmented, possess rather small eyes and very elongate antennae, character states which are typically associated with subterranean or cavicolous habits. Both species, although quite differently shaped, seem to be nearest related to *P. rufopiceus* Baehr, recorded from a cave in the northern part of the Northern Territory. These species are included in a revised key to the Australian species of the genus *Pogonoglossus*.

KEYWORDS: taxonomy, morphology, Western Australia, cavicolous

INTRODUCTION

Physocrotaphini (formerly also called Helluodini) is a small tribe of characteristically shaped carabid beetles that occurs with c. 40 described species in the Oriental and Papuan-Australian Regions (Lorenz 2005). The affinities of the tribe are still uncertain (Moore 1998), but it may be more closely related to the mainly Afrotropical Anthiini than to any other tribe. The Oriental species of the most diverse genus *Pogonoglossus* urgently require revision, because species identification without comparison with types is presently barely possible, and, in addition, because several additional species are believed to exist. The species from New Guinea were worked on by Darlington (1968) in his monumental monograph on the New Guinean Carabidae, and the Australian species were revised by Baehr (1988). Since that time, however, a few additional species have been described from both New Guinea and Australia (Baehr 1993, 1995, 2005, 2008).

Only the genus *Pogonoglossus* is recorded from Australia but specimens are rarely collected. Therefore almost nothing is known about the habits and life histories of any Australian species. Of the presently described species, the five pigmented ones have been most commonly collected at light in open eucalyptus forest, tropical savannah, and 'dry rain forest'. One specimen was recorded as being sampled from under bark of a log. The single described rufous species, *P. rufopiceus* Baehr, 1993, was collected in a cave.

Thanks to the courtesy of Nadine Guthrie, Brian Hanich and Nikolai Tatarnic (Perth) I received a small sample of carabid beetles from different tribes for identification that were collected during a survey in some mining areas in the Pilbara, north-western Western Australia. All specimens were sampled by 'trog scrape' which means that troglobiotic animals were collected from drill bores in the ground in iron ore mining areas as described by Halse and Pearson (2014) and as noted below. As a consequence, the sample consists of more or less depigmented specimens with small eyes or even without visible eyes. Included in the sample are specimens from the tribes Physocrotaphini, Zuphiini, and Bembidiini, subtribe Anillina. Both Zuphiini and Anillina are known to have several soil or cave inhabiting species. Known members of the tribe Physocrotaphini are often regarded as forest inhabiting beetles, however, in Australia one species has been recorded from a cave

In this paper two new species of the tribe Physocrotaphini are described.

http://www.zoobank.org/urn:lsid:zoobank.org:pub:B402B16D-1966-402B-A9DC-52C38F25B705

METHODS

In the taxonomic survey standard methods are used. The genitalia were removed from specimens relaxed for a night in a jar under moist atmosphere, then cleaned for a short while in hot 10% KOH. Specimens are very fragile because they are preserved in 100% ethanol, so instead of photographs the habitus of head and pronotum is depicted in drawings.

Measurements were taken using a stereo microscope with an ocular micrometer. Length has been measured from apex of labrum to apex of elytra. Length of pronotum was measured in a straight line from the apex of the anterior angles to the most produced part of the base. Length of the elytra was measured from the most advanced part of the humerus to the very apex.

The holotypes of the new species are stored in Western Australian Museum, Perth (WAM).

COLLECTING METHOD

Halse and Pearson (2014) describe extensively a method of sampling subterranean, but not cavicolous, arthropods living in the earth, during a survey carried out in iron ore mining areas in the Pilbara, north-western Australia. The collectors used nets which were lowered into drill bores in the ground and then pulled out again. During the lifting of the net from the hole, the margins of the bores were scraped by the net and animals that fell inside were brought to the surface. For the carabid species worked on in the present paper, this was done in depths of up to 43 m below surface level. According to the authors this collecting method in general was more successful than the method of sampling animals in the drill bores by pitfall traps.

TAXONOMY

Family Carabidae Latreille, 1802

Subfamily Harpalinae Bonelli, 1810

Tribe Physocrotaphini Chaudoir, 1862

Genus *Pogonoglossus* Chaudoir, 1862

Pogonoglossus Chaudoir, 1862: 304.

TYPE SPECIES

Pogonoglossus validicornis Chaudoir, 1862, by monotypy.

REMARKS

Pogonoglossus is the commonest genus of Physocrotaphini and is covers by far the largest number of species. All species are markedly depressed and rather elongate, possess a large head with elongate mandibles, a wide, cordiform prothorax, and parallel-sided elytra.

Most Australian species occur in north-eastern Queensland, only *P. porosus* Sloane has been also recorded from the northernmost parts of Northern Territory and Western Australia, and the cave inhabiting *P. rufopiceus* Baehr is only known from the vicinity of Katherine, Northern Territory. The two new species enlarge the range of the genus in Australia to the Pilbara Region.

Pogonoglossus frater sp. nov.

Figures 1, 3

http://www.zoobank.org/urn:lsid:zoobank.org:act:1C95C5B5-734E-4F51-9B73-9FE898DC9DA8

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** ♂, 'W.A.: Mining Area C, c. 96 km WNW. Newman 22°54′33.50″S 118°56′36.80″E (WGS 84) 24 June 2010 M.K. Curran, G.B. Pearson (PSC0165R) Trog scrape' (WAM E88466).

DIAGNOSIS

With its pale colouration, relatively small eyes and elongate antenna, this species is quite similar to *P. soror* sp. nov. and *P. rufopiceus*. It is distinguished from *P. soror* by its larger body size, wider prothorax, and shorter elytra, and from *P. rufopiceus* by smaller eyes, wider pronotum with narrower base, shorter elytra, and longer antenna.

DESCRIPTION

Measurements: Length: 8.3 mm; width: 2.95 mm. Ratio width of base/width of apex of pronotum: 1.13; ratio width/length of pronotum: 1.26; ratio width of pronotum/width of elytra: 0.72; ratio length/width of elytra: 1.64; ratio length/width of 10th antennomere: 3.2.

Colour: Head and pronotum reddish. Elytra reddish-piceous, the lateral margin narrowly pale red. apical margin of clypeus, labrum, and mandibles piceous. Femora dirty yellow, undersurface of tibiae and tarsi reddish-piceous. Lower surface pale red, head and pronotum, and apical part of abdomen slightly darker.

Head (Figure 1): Slightly narrower than pronotum, wide between eyes. Eye comparatively small, shorter than orbit, laterad but moderately protruded. Frons with a shallow, semicircular, median impression behind clypeal suture, neck separated by a deep, convex furrow. At posterior border of eye a small boss. Behind and slightly below this boss a fairly deep suture, below that with a protuberance that bears c. 3 elongate setae at tip. This protuberance is projected laterad almost as far as eye, the suborbital curvature very convex, longer than eye. Mandibles fairly elongate, inner border almost straight, incurved near apex. Palpi moderately elongate, slightly widened apicad, sparsely setose. Lateral parts of mentum laterad triangularly protruded, with two elongate setae. Antenna very elongate, scapus elongate, about as long as width of base of clypeus, 5th to 7th antennomeres > 3 x as long as wide. Surface of head sparsely, though rather coarsely punctate and pilose, pilosity very short and inclined anteriad. Microreticulation absent, surface very glossy.

Prothorax (Figure 1): Large and rather wide, much wider than long, markedly cordiform, widest at apical third. Apex wide, slightly concave, anterior angles produced, at tip slightly obtuse. Lateral margins regularly convex, in basal fourth straight and parallel-sided. Basal angles slightly more than rectangular, near tip slightly concave, the very tip being a very small denticle. Base comparatively narrow, in middle straight, laterally slightly oblique. Lateral margin slightly raised, marginal explanation wide. Apex indistinctly margined, base not margined. Disk gently convex. Median line fine, slightly impressed, neither attaining apex nor base. Both transverse sulci very shallow. Basal grooves shallow, wide. Lateral margin without a visible lateral seta, but at least the puncture of the basal seta visible. Surface with moderately dense, fairly coarse, but shallow punctures, and with dense, short, slightly declined pilosity. Microreticulation extremely fine and superficial, composed of more or less isodiametric meshes.

Elytra: Elongate and parallel-sided, but comparatively short (in genus); dorsal surface depressed. Humerus little projected, rounded. Lateral margins straight. Apex slightly concave and slightly oblique; external apical angle widely rounded. Striae complete and well impressed, intervals raised, fairly densely punctate in 2–3 rows, punctures slightly rasp-shaped. Pilosity fairly dense, depressed. Microreticulation distinct, slightly transverse. Marginal setae very elongate. Metathoracic wings apparently complete.

Lower surface: Densely punctate and pubescent. Metepisternum elongate, c. 2 x as long as wide at apex. Terminal sternite in male on either side with one seta in middle (but setae broken) and with 3 setae near apical border.

Legs: Elongate. All tibiae very densely setose with longer and shorter hairs. Also tarsi pilose on upper and lower surfaces. Three basal tarsomeres of the male protarsus little widened, sparsely, biseriately pilose.

Male genitalia (Figure 3)*:* Genital ring wide, triangular but slightly convex, slightly asymmetric, with very wide base. Aedagus short and compact, slightly asymmetric; lower surface straight. Apex short and wide, asymmetrically, obtusely triangular-convex. Orificium elongate, dorsally on either side with a sclerotised rod. Internal sac with several folds and with two complexly twisted, narrow, sclerotised pieces. Parameres very dissimilar, left paramere large, compact, right paramere narrow, with elongate, hooked peduncle, both asetose at apex.

Female gonocoxites: Unknown.

Variation: Unknown.

DISTRIBUTION

This species is known only from the type locality north-west of Newman in the Pilbara region of north-western Western Australia.

REMARKS

The holotype was sampled by 'trog scrape' as discussed above under 'Collecting method', but the depth of the bore was not stated.

This species is probably closely related to *P. soror* and *P. rufopiceus*. However, as the male genitalia of both of these species are yet unknown, and because all three species are depigmented because of their habits as cavicolous or soil-inhabiting species, any similarities might simply be due to homoplasy.

ETYMOLOGY

The name means 'brother' and refers to the fact that the holotype is a male.

Pogonoglossus soror sp. nov.

Figures 2, 4

http://www.zoobank.org/urn:lsid:zoobank.org:act:6C76DFAE-742F-49EA-89CD-FEC276F0958F

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , 'W.A.: Kutayi, c. 71 km S. Nullagine 22°31′24.4″S 120°01′59.2″E (WGS 84) 27 August 2013 J.S. Cocking, J.W. Quartermaine (BH0034) Trog scrape, 43 m' (WAM E88467).

DIAGNOSIS

With its pale colouration, small eyes, and elongate antenna this species is quite similar to *P. frater* and *P. rufopiceus.* It is distinguished from *P. frater* by its smaller body size, narrower prothorax, and longer elytra, and from *P. rufopiceus* by its smaller eye, narrower pronotum, slightly longer elytra, and longer antenna.

DESCRIPTION

Measurements: Length: 6.3 mm; width: 2.1 mm. Ratio width of base/width of apex of pronotum: 1.22; ratio width/length of pronotum: 1.15; ratio width of pronotum/width of elytra: 0.65; ratio length/width of elytra: 1.76; ratio length/width of 10th antennomere: 3.2.

Colour: Head and pronotum pale reddish, elytra very slightly darker, the lateral margin narrowly dirty yellow. Legs yellow, tibiae and tarsi barely darker. Lower surface pale red.

Head (Figure 2): As wide as pronotum, wide between eyes. Eye comparatively small, shorter than orbit, laterad rather protruded. Frons with a shallow, about quadrate, median impression behind clypeal suture, neck separated by a deep, curved furrow. At posterior border of eye a small boss. Behind and slightly below this boss a shallow suture, below that with a very small protuberance that bears c. 3 elongate setae at tip. This protuberance is far less projected laterad than eye, the suborbital curvature very convex, longer than eye. Mandibles comparatively short, inner border almost straight, only incurved near apex. Palpi moderately elongate, slightly widened apicad, sparsely setose. Lateral parts of mentum laterad triangularly protruded,

with two elongate setae. Antenna very elongate, scapus elongate, about as long as width of base of clypeus, 5th to 7th antennomeres > 3 x as long as wide. Surface of head sparsely but rather coarsely punctate and pilose, pilosity very short and inclined anteriad. Microreticulation absent, surface very glossy.

Prothorax (Figure 2): Rather narrow, slightly wider than long, markedly cordiform, widest at apical fourth. Apex wide, almost straight, anterior angles little produced, rounded. Lateral margins in apical three fifths regularly convex, in basal two fifths straight and parallel-sided. Basal angles almost rectangular, near tip extremely slightly concave, the very tip being a small but distinct denticle. Base comparatively wide, in middle straight, laterally fairly oblique. Lateral margin slightly raised, marginal explanation moderately wide. Both apex and base not margined. Disk gently convex. Median line distinct, slightly impressed, neither attaining apex nor base. Both transverse sulci very shallow. Basal grooves shallow, wide. Lateral margin without a visible lateral seta, but at least the puncture of the basal seta visible. Surface with moderately dense, coarse, but shallow punctures that are arranged in about transverse rows, with short, slightly declined pilosity. Microreticulation fine and superficial, composed of more or less isodiametric meshes.

Elytra: Elongate and parallel-sided, narrow; dorsal surface depressed. Humerus little projected, rounded. Lateral margins straight. Apex slightly concave and slightly oblique; external apical angles widely rounded. Striae complete and well impressed, intervals raised, fairly densely punctate in about two rows, punctures slightly rasp-shaped. Pilosity fairly dense, depressed. Microreticulation distinct, slightly transverse. Marginal setae very elongate. Metathoracic wings apparently complete.

Lower surface: Densely punctate and pubescent. Metepisternum elongate, slightly > 2 x as long as wide at apex. Terminal sternite in female on either side with one elongate seta in middle and with 3–4 setae near apical border.

Legs: Elongate. All tibiae very densely setose with longer and shorter hairs. Also tarsi pilose on upper and lower surfaces. Vestiture of male protarsus unknown.

Male genitalia: Unknown.

Female gonocoxites (Figure 4): Gonocoxite 1 elongate, with 3–4 short, ensiform seta at median apical rim. Gonocoxite 2 rather elongate, curved, with acute apex, with 2 small ensiform setae in the apical half of the ventro-lateral surface, one fairly elongate, strong nematiform seta in the basal half of the dorso-median surface, and a short nematiform seta at the apical fourth of the dorso-median surface that originates from a pit. Lateral plate sclerotised and at apical rim with c. 8 very elongate nematiform setae.

Variation: Unknown.

DISTRIBUTION

This species is known only from the type locality south of Nullagine in the Pilbara region of north-western Western Australia.

REMARKS

The holotype was sampled by 'trog scrape' as discussed above under 'Collecting method', at 43 m below surface.

For relationships see under *P. frater*.

ETYMOLOGY

The name means 'sister' and refers to the fact that the holotype is a female.

Revised key to the Australian species of *Pogonoglossus*

1\. Orbit behind or below eye with a distinct tuberosity and/or a tooth; base of pronotum laterally perceptibly oblique 2

Orbit behind or below eye without tuberosity or tooth; base of pronotum laterally almost straight (NE. Queensland)......... *P. inarmatus* Baehr, 1988

2\. Orbit **behind** eyes with a tooth or tuberosity 3

Orbit **below** eyes with a tooth or tuberosity, separated by a furrow... 5

3\. Orbital tooth tiny; intervals of elytra glossy, punctation uni- to biseriate (c. New South Wales). ....*P. danielsi* Baehr, 2008

Orbital tooth large; intervals of elytra distinctly microreticulate, punctation three- to quadriseriate (E. Queensland).. 4

4\. Body size larger, 8.7–10.4 mm; orbit markedly swollen, almost as long as eye, posteriorly gently curved, laterally projected beyond eye; lateral border of pronotum widely explanate; antenna elongate, terminal antennomeres >2 x as long as wide (E. Queensland) .... *P. inflaticeps* (Sloane, 1904)

Body size smaller, 7.2–8.7 mm; orbit less swollen, c. half of length of eye, posteriorly almost transverse, laterally much less projected than eye; lateral border of pronotum narrow, not explanate; antenna short, terminal antennomeres c. 1.5 x as long as wide (New Guinea; E. Queensland: Cape York Peninsula) .... *P. parvus* Darlington, 1968

5\. Colour dark piceous; eye larger, though laterally less projected, longer than orbit; suborbital tuberosity laterally much more projected; antenna shorter, scapus distinctly shorter than width of base of clypeus, terminal antennomeres < 2.25 x as long as wide (E. Queensland; N. Northern Territory; N. Western Australia north of Great Sandy Desert) .... *P. porosus* (Sloane, 1904)

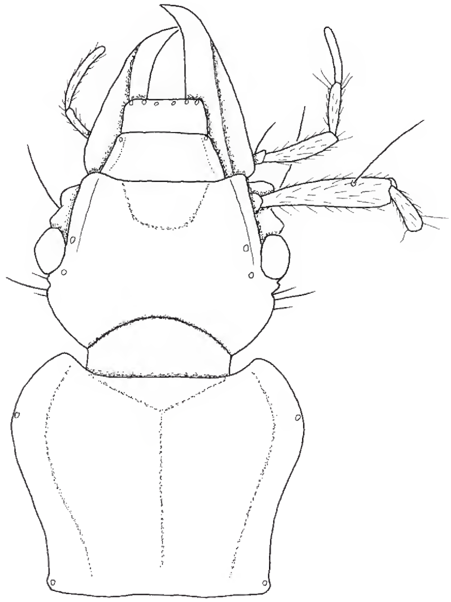

FIGURE 1 Head and pronotum of *Pogonoglossus frater* sp. nov. Scale bars = 1 mm.

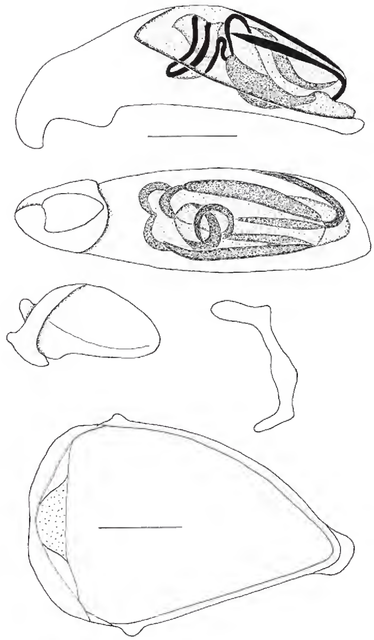

FIGURE 3 *Pogonoglossus frater* sp. nov., male aedeagus, left side and lower surface, parameres, genital ring. Scale bars = 0.25 mm.

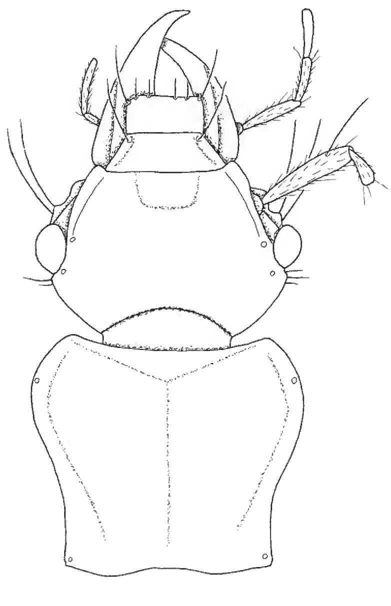

FIGURE 2 Head and pronotum of *Pogonoglossus soror* sp. nov. Scale bars = 1 mm.

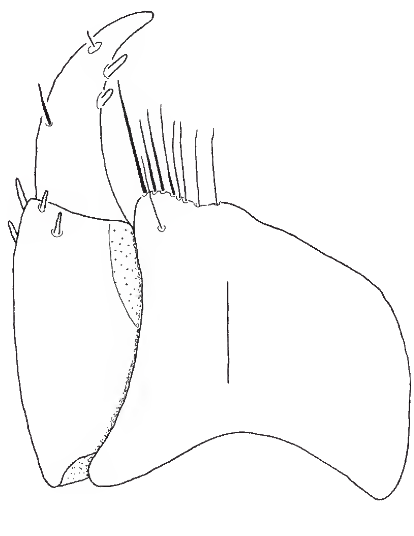

FIGURE 4 *Pogonoglossus soror* sp. nov., female gonocoxites and lateral plate. Scale bar = 0.1 mm.

Colour more or less pale red; eye smaller, as long as orbit, or shorter, though laterally more projected; suborbital tuberosity laterally much less projected; antenna longer, scapus almost as long as width of base of clypeus, or longer, terminal antennomeres > 2.5 x as long as wide 6

6. Body size larger, > 8 mm; pronotum wider, ratio width/length > 1.2 7

Body size smaller, < 6.3 mm; pronotum narrower, ratio width/length 1.15 (Figure 2) (NW. Western Australia: Pilbara)........................ *P. soror* sp. nov.

7. Pronotum wider, with narrower base, ratio width/length of pronotum 1.26, ratio base/apex 1.13; elytra shorter, ratio length/width 1.64; eye laterad less produced (Figure 1); antenna longer, terminal antennomeres > 3 x as long as wide (NW. Western Australia: Pilbara)....................... *P. frater* sp. nov.

Pronotum narrower, with wider base, ratio width/length of pronotum 1.20, ratio base/apex 1.24; elytra longer, ratio length/width 1.73; antenna shorter, terminal antennomeres c. 2.55 x as long as wide (N. Northern Territory) .... *P. rufopiceus* Baehr, 1993

REMARKS

Most Australian species of *Pogonoglossus* are known from eastern Australia, i.e. from Iron Range in North Queensland to central eastern New South Wales; only *P. porosus* (Sloane, 1904) occurs across the tropical belt from North Queensland to the Kimberleys in far northern Australia, and the cavicolous *P. rufopiceus* is known from near Katherine in the northern part of the Northern Territory. Therefore, the discovery of two new species in the Pilbara, south of the Great Sandy Desert, is surprising, and considerably enlarges the range of the genus in Australia. The occurrence is surprising, because the genus *Pogonoglossus* certainly is an Oriental faunal element, species of which immigrated into Australia from the north, most probably from New Guinea via Cape York Peninsula. This immigration occurred rather recently, after the contact of Australia with the South Asian insular belt, and the immigration seems to continue, because one species, *P. parvus* Darlington, 1968, that was originally described from New Guinea, occurs in the Iron Range in mid Cape York Peninsula. This is an area well known for a number of species being conspecific with species occurring in New Guinea and the Oriental Region, or being still very closely related to such species. Thus, they seem to represent rather recent immigrants to Australia. Occurrence of such northern, 'Torresian' faunal elements in Western Australia south of Great Sandy Desert is surprising and very uncommon, and thus, the two new species are of major importance for biogeographic questions.

Those species of Physocrotaphini of which any knowledge about their habits is available, usually occur in open to closed forests, and probably they live under bark of trees and logs or in other crevices. Only a single species so far is known to have been found in a cave, the northern Australian *P. rufopiceus* Baehr, but outside of Australia no cavicolous or subterranean species of Physocrotaphini are known. Therefore the detection of two small eyed, depigmented, true humicolous species is important and enlightens our restricted knowledge about the habits of this carabid group.

This discovery of two soil inhabiting species also demonstrates our restricted knowledge not only of the fauna of north-western Australia, but particularly of the Australian cave and subterranean fauna in general. Application of the sampling method as used during the mentioned survey even more systematically and in other parts of Australia might considerably enlarge the number of such subterranean species, and thus might noticeably change our knowledge about the composition of the Australian carabid fauna in a same way as it happened by the discovery of the rich beetle fauna living in wells and generally in subterranean waters.

It should be mentioned that during the same survey also some depigmented, soil inhabiting Zuphiini and Anillina (Bembidiini) were found which presently are under examination.

ACKNOWLEDGEMENTS

I am indebted to Nadine Guthrie, Brian Hanich, and Nikolai Tatarnic (Perth) for the loan of the specimens, and to Dean Main (Perth) for additional information about sampling methods.

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MANUSCRIPT RECEIVED 5 JUNE 2014; ACCEPTED 13 NOVEMBER 2014.

Three new species and a new genus of subterranean Zuphiini from the Pilbara region of north-western Australia (Coleoptera: Carabidae: Harpalinae)

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ABSTRACT – Three new carabid species of the zuphiine genera *Parazuphium* Jeannel, subgenus *Austrozuphium* Baehr, and *Typhlozuphium* gen. nov. are described from the Pilbara in north-western Australia: *Parazuphium pilbarae* sp. nov. *Typhlozuphium humicolum* sp. nov. and *T. longipenne* sp. nov. The new species were detected in the course of a survey for subterranean insects in mining areas and were collected by 'trog scrape'. All three species are depigmented and possess very elongate antennae, character states that subterranean or cavicolous carabid species tend to develop) *Parazuphium pilbarae* has small eyes and is probably related to *Parazuphium* (*Austrozuphium*) *flavescens* Baehr from the Kimberleys. Both *Typhlozuphium* species are blind and are further characterised by very long legs, elongate, posteriad barely widened head, and very elongate, parallel-sided elytra which lack the sinuate apex that is characteristic for species of the subgenus *Austrozuphium*.

KEYWORDS: taxonomy, new genus, new species, Western Australia, Carabidae, Zuphiini, *Parazuphium, Typhlozuphium*

INTRODUCTION

Zuphiini is a moderately large tribe of quite variously shaped carabid beetles which are characterised by their depressed body, wide head with a remarkably narrow 'neck', and usually very elongate scapus of the antenna. The limits of Zuphiini as well as their subdivision into subtribes are still controversially discussed; in particular the relationships of the subtribe (or tribe) Planetina (-ini) are unresolved (see Habu 1967, Lorenz 2005, Bouchard et al. 2011). In Australia the subtribes Leleupidiina, Dicrodontina, Zuphiina, and Planetina occur, according to the subtribal classification of Lorenz (2005).

Zuphiini occur in all zoogeographical regions, but are most common in tropical and subtropical areas. The Australian Zuphiines were revised by Baehr (1984, 1985a, 1985b, 1986a, 1986b, 1988), but since these papers, several additional species have been described by Baehr (1992, 1995, 2001, 2008a, 2008b, 2010, 2012) and Moore (1995). Presently, eight genera including 51 species and subspecies are recorded from Australia. Most species occur in the tropical belt across northern Australia.

Rather little is known about life histories and habits of Zuphiini, including the Australian species, but the tribe is renowned for the edaphic life of all species, with great numbers of species living either in leaf litter of rain forests, in soil, or in caves. Most presently known Australian species are large-eyed and darkly coloured. They are typically strictly nocturnal species that live under cover on the ground and they are normally only detected at light. The two known species of the genera *Speothalpius* and *Speozuphium* described by Moore (1995) are blind, depigmented, cavicolous beetles found in the Nullarbor Plain. Some other species of *Parazuphium* Jeannel, of the subgenus *Austrozuphium* Baehr, are more or less depigmented and possess smaller eyes and longer antennae than most known zuphiines, e.g. *P. flavescens* Baehr, 1985 from far north-western Australia (Baehr 1985). The single Australian species of the subtribe Leleupidiina, *Colasidia monteithi* Baehr, 1988, is a small, depigmented, small-eyed species that was found in leaf litter in a North Queensland rain forest (Baehr 1988). The subtribe Dicrodontina includes 12 species of the phylogenetically plesiotypic genus *Acrogenys* Macleay, 1864 which exclusively occur in northern Australia from north-eastern Queensland to the Pilbara in northern Western Australia.

The new genus and three new species described in the present paper belong to the subtribe Zuphiina which in

http://www.zoobank.org/urn:lsid:zoobank.org:pub:4370D422-3DB8-4BED-B8F8-63773C18E79F

Australia includes the genera *Pseudaptinus* Castelnau, 1834, *Zuphium* (s. str.) Latreille, 1806, *Parazuphium* Jeannel, 1942, and probably also *Speozuphium* Moore. 1995 and *Speothalpius* Moore. 1995.

By courtesy of Nadine Guthrie, Brian Hanich, and Nikolai Tatarnic (Perth) I received a small sample of carabid beetles for identification. The specimens were collected during a survey of mining areas in the Pilbara, north-western Western Australia. All specimens were sampled by 'trog scrape'. This is a method of sampling troglobiotic animals from drill bores in the ground in iron ore mining areas as described by Halse and Pearson (2014). As a consequence, the sample consists of depigmented specimens with small eyes or without visible eyes. Included in the sample are specimens from the tribes Physocrotaphini, Zuphiini, and Bembidiini, subtribe Anillina. Both Zuphiini and Anillina are known to have several soil or cave inhabiting species.

In this paper three new species and a new genus of Zuphiini are described.

METHODS

In this taxonomic survey standard methods were used. Genitalia were removed from specimens and relaxed overnight in a jar under moist atmosphere. They were then cleared for a short while in a hot bath of 10% KOH. Specimens were very fragile due to being preserved in 100% ethanol so only a single pinned specimen was photographed. For better presentation of essential characters the habitus of the head and pronotum is illustrated. The habitus photograph was obtained with a digital camera using ProgRes CapturePro 2.6 and AutoMontage, and was edited with Corel Photo Paint X4.

Measurements were taken using a stereo microscope with an ocular micrometer. Body length was measured from apex of labrum to apex of elytra. Length of pronotum was measured in a straight line from the apex of the anterior angles to the most produced part of the base. Length of the elytra was measured from the most advanced part of the humerus to the very apex.

The types of the new species are stored in Western Australian Museum, Perth (WAM), except one paratype which is stored in the working collection of the author at Zoologische Staatssammlung München (CBM).

COLLECTING METHOD

During a survey carried out in iron ore mining areas in the Pilbara, north-western Australia (Halse and Pearson 2014) describe extensively, their method of sampling subterranean fauna. The collectors used nets which were sunken into drill bores in the ground and then lifted out again, at which the margins of the bores were scraped by the net and arthropods living in the earth were brought to the surface. For the carabid species worked in the present paper this was done in depths of up to 60 m below surface level. According to the authors this collecting method in general was more successful than sampling animals in the drill bores using pitfall traps.

TAXONOMY

Family Carabidae Latreille, 1802

Subfamily Harpalinae Bonelli, 1810

Tribe Zuphiini Bonelli, 1810

Subtribe Zuphiina Bonelli, 1810

REMARKS

In this paper, a new species of the genus *Parazuphium* Jeannel, subgenus *Austrozuhpium* Baehr, 1985 and two species of the new genus *Typhlozuphium* are described from the Pilbara Region. From this area one species each of *Parazuphium* s. str. and of the subgenus *Austrozuphium* have been recorded, in addition to single species of the genera *Acrogenys* Macleay, *Pseudaptinus* Castelnau, *Zuphium* Latreille, and *Planetes* Macleay.

Genus *Parazuphium* Jeannel, 1942

Parazuphium Jeannel 1942: 1095; Baehr 1985b: 298; Baehr 2001: 85; Lorenz 2005: 506.

TYPE SPECIES

Zuphium chevrolati Castelnau, 1833, by original designation.

DIAGNOSIS

Genus of subtribe Zuphiina. Rather small, depressed, usually yellow to brown species; eyes present, moderately sized to rather small: antenna elongate with elongate scapus; 1st antennomere more than 1.5 x as long as 2nd and 3rd antennomeres together, with several erect setae; elytral striae indistinct; aedeagus short and compact; gonocoxite 2 falciform, asetose.

REMARKS

The genus is widely distributed in the Palearctic, Afrotropical, Oriental, and Papuan-Australian Regions (Lorenz 2005).

Parazuphium (Austrozuphium) Baehr, 1985

Austrozuphium Baehr 1985: 307; Lorenz 2005: 507.

TYPE SPECIES

Zuphium mastersii Castelnau, 1867, by original designation.

DIAGNOSIS

As for genus; head with a single seta behind the eye; elytral striae very feeble; apex of elytra distinctly

sinuate and moderately incurved towards suture; aedeagus compact and usually heavily sclerotised, with very short orificium and with two short, sclerotised plates in the opening.

REMARKS

This subgenus is exclusively Australian (Baehr 1985). Presently five species are known which occur from eastern South Australia through the whole of eastern Australia, the northern parts of Northern Territory, to the Pilbara in north-western Western Australia.

Parazuphium (*Austrozuphium*) *pilbarae* sp. nov.

Figures 1, 4

http://www.zoobank.org/urn:lsid:zoobank.org:act:A14C1137-72FC-4694-9E0B-89AEF70D9225

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , 'W.A.: Flinders Mine, c. 73 km NNW. Tom Price 22°08′14.60″S 117°25′28.60″E (WGS 84) 07 Feb. 2012 J.S. Cocking, G.B. Pearson (HPRC0930) Trog scrape, 17 m' (WAM E88463).

DIAGNOSIS

Yellow, depressed species with elongate, somewhat cordiform pronotum and small eyes; distinguished from the very similar *P. flavescens* Baehr, 1985 from the Kimberleys by smaller, laterad virtually not produced eye, slightly longer median antennomeres, slightly laterad produced basal angle of pronotum, and shortened metathoracic wings.

DESCRIPTION

Measurements: Length: 3.5 mm; width: 1.25 mm. Ratio width/length of pronotum: 1.24; ratio width of widest diameter/width of baser of pronotum: 1.86; ratio width of head/width of pronotum: 0.96; ratio length/width of elytra: 1.53; ratio length/width of scapus: 6.6; ratio length/width of 6th antennomere: 4.0.

Colour: Upper and lower surfaces dirty yellow, palpi, antenna, and legs even slightly paler.

Head (Figure 1): Almost as wide as pronotum, relatively short and wide, wide between eyes. Upper surface gently convex. Eye very small, laterad virtually not protruded. Frons with a very small, inconspicuous, impression on either side just behind the clypeal suture. Neck very narrow, separated by a deep, convex furrow. Clypeus bisetose, setae elongate. Labrum slightly concave at apex, 6-setose. Mandibles short and wide, scrobe with some fairly elongate setae. Palpi narrow and elongate, slightly widened apicad, rather densely pilose, in particular the basal palpomere of the maxillary palpus rather hirsute. Antenna very elongate, scapus elongate, about as long as diameter of head, with several elongate setae, densely pilose; median antennomeres > 4 x as long as wide. Posterior supraorbital seta far removed from posterior margin of eye. Surface of head sparsely, though rather coarsely punctate and pilose, pilosity very short and inclined anteriad. Microreticulation fine and superficial, about isodiametric.

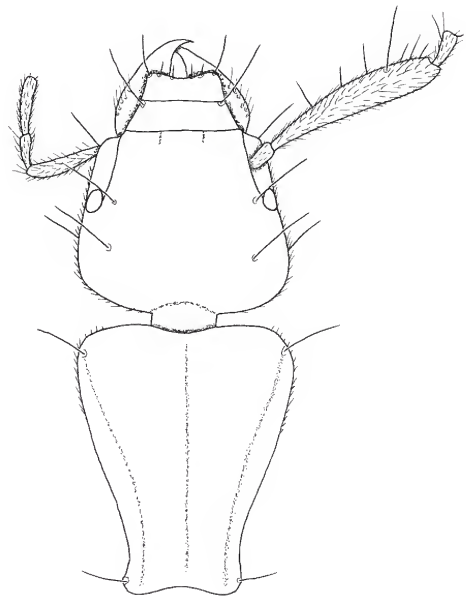

FIGURE 1 Head and pronotum: 1, *Parazuphium pilbarae* sp. nov. Scale bars = 1 mm.

Prothorax (Figure 1): Narrow and elongate, much longer than wide, cordiform, widest close to apex. Apex wide, straight, apical angles rounded, shortly pilose. Lateral margin in apical two thirds oblique and gently convex, in basal third straight and slightly concave. Basal angles slightly triangularly produced, situated slightly in front of base. Base narrow, almost straight. Lateral marginal explanation very shallow, inconspicuous. Both, apex and base not margined. Disk rather depressed. Median line very fine, slightly impressed, almost attaining apex and base. No transverse sulci visible. Basal grooves shallow, narrow. Anterior marginal seta situated shortly behind apical angle, posterior seta situated on the basal angle. Surface with moderately dense, fairly coarse, but very shallow punctures, and with dense, short, slightly declined pilosity. Microreticulation extremely fine and superficial, composed of more or less isodiametric meshes.

Elytra: Fairly elongate and but slightly widened apicad; dorsal surface depressed. Humerus oblique-convex. Lateral margins straight and very slightly oblique. Apex distinctly sinuate, slightly oblique, markedly incurved towards suture; external apical angles widely rounded. At least the internal striae just perceptible though barely impressed, internal intervals in basal half very slightly raised. Surface with dense and slightly rugose punctures in 2–3 rows. Pilosity fairly dense but very short, depressed. Microreticulation distinct, slightly transverse. Marginal setae very elongate. Metathoracic wings slightly shortened.

Ventral surface: Densely punctate and pubescent. Metepisternum rather wide, c. 1.5 x as long as wide at apex. Terminal sternite in male with one elongate seta on either side.

Legs: Narrow and elongate, densely pilose. Tarsi pilose on upper and lower surfaces. 4th tarsomeres widened and deeply cleft. Three basal tarsomeres of the male protarsus sparsely, biseriately pilose.

Male genitalia (Figure 4): Genital ring strongly sclerotised, wide, almost quadrangular, with wide base and apex. Aedeagus very short and compact, very heavily sclerotised, markedly curved as well in vertical as horizontal directions. Apex short and rather wide, obtusely triangular. Orificium short, situated on the left side, dorsally on either side with a short, sclerotised plate. Internal sac with some extremely heavily sclerotised folds some of which are slightly denticulate; parameres small, very dissimilar.

Female gonocoxites: Unknown.

Variation: Unknown.

DISTRIBUTION

This species is known only from the type locality in the Pilbara region of north-western Western Australia.

REMARKS

The holotype was sampled by 'trog scrape' as discussed above under 'Collecting method', at 17 m below the surface.

According to the body shape and structure this species is most similar to *P. flavescens* Baehr, 1985, from the Kimberley region of north-western Australia. Unfortunately, of that rare species so far only females have been recorded, therefore the putative relationship cannot be corroborated by comparison of the male genitalia.

ETYMOLOGY

The name refers to the region where the species was detected, the Pilbara in north-western Australia south of Great Sandy Desert.

Genus *Typhlozuphium* gen. nov.

http://www.zoobank.org/urn:lsid:zoobank.org:act:8F994D45-545D-43F2-B8C3-64851A439507

TYPE SPECIES

Typhlozuphium humicolum sp. nov.

DIAGNOSIS

A genus of the subtribe Zuphiina; characterised by narrow and elongate, posteriad barely widened but widely rounded head, lacking eyes, deeply excised labrum, very small, anteriorly convex clypeus which bears a third, median seta, presence of a single 'supraorbital' seta, cordiform, asetose prothorax with laterally well visible proepisternum, narrow and elongate, almost parallel-sided, dorsally rather convex elytra with oblique, not sinuate nor incurved apex, very elongate legs, comparatively elongate aedeagus with wide apex and elongate, sclerotised rods at the top of the internal sac, falciform, asetose gonocoxite 2, and remarkably elongate setae at the upper ventral rim of gonocoxite 1.

DESCRIPTION

Colour: Upper and lower surfaces, palpi, antenna, and legs pale yellow.

Head: Elongate, slightly wider than pronotum, posteriad little widened, about elliptical, widely rounded towards neck. Eye absent. Neck short, narrow, separated by a deep furrow. Clypeus small, apical margin convex, trisetose, i.e. with a slightly shorter seta in middle, lateral setae elongate. Labrum deeply concave at apex, 6-setose, the lateral seta longer than the median ones. Mandibles comparatively elongate, wide, at apex suddenly incurved, lateral margin near base with several elongate setae. Palpi narrow and elongate, apical palpomeres slightly widened apicad, palpi densely pilose; the basal palpomere of the maxillary palpus hirsute, the basal palpomere of the labial palpus at apex with several elongate setae. Mentum with a quadrate tooth, 4-setose behind the tooth. Labium short, glossa wide at apex, paraglossae apparently fused to glossa, at apex 5-setose. Lacinia elongate, median margin with many elongate, stout setae. Galea narrow and elongate, impilose. Antenna very elongate, scapus longer than diameter of head, with one elongate seta near apex and several very short, erect setae within the fairly dense, depressed pilosity; median antennomeres with very dense, adpressed, very short pilosity. One supraorbital seta present, situated at apical third of head. Surface of head sparsely punctate and pilose, pilosity on surface short and inclined anteriad, laterally longer. Microreticulation fine and superficial, about isodiametric.

Prothorax: Rather narrow and elongate, much longer than wide, cordiform, widest at or slightly in front of middle. Apex in middle straight, laterally markedly oblique; apical angles obtusely rounded. Lateral margin

in basal half concave, near base straight. Basal angles slightly removed from base, very slightly triangularly produced. Base rather narrow, in middle slightly concave. Lateral margin slightly carinate, marginal explanation in apical half narrow and shallow, in basal half slightly wider and deeper. Both, apex and base not margined. Disk depressed but uneven, in apical half slightly convex, in basal half slightly impressed. Median line fine, inconspicuous, almost attaining apex and base. Basal grooves shallow, rather elongate. In middle of pronotum proepisternum well visible from above, wide and convex, producing the widest diameter of pronotum. No marginal setae or punctures visible. Surface with dense, coarse, transverse furrows, interrupted by rather dense punctures, with fairly dense, short, declined pilosity. Microreticulation extremely fine and superficial, composed of more or less isodiametric meshes.

Elytra: Elongate and parallel-sided or almost so; dorsal surface convex but depressed on disk. Humerus oblique. Lateral margins straight. Apex very oblique, not sinuate, not incurved at suture, narrowly marginate; external apical angles widely rounded. At least two median striae just perceptible though barely impressedNo discal punctures and setae visible. Lateral marginal setae extremely elongate, composed of two groups: 4 setae behind humerus, 2 setae near external apical angle. Surface with dense and rasp-like punctation. Pilosity dense, fairly elongate, declined posteriad. Microreticulation distinct, isodiametric. Surface rather dull. Metathoracic wings completely reduced.

Lower surface: Moderately densely punctate and pilose. Pilosity rather elongate, on head and prothorax inclined anteriad, on abdomen inclined posteriad. Metepisternum short, little longer than wide at apex. 1st visible abdominal sternite very elongate, almost as long behind metacoxa as the three following sternites. Terminal sternite in both sexes with one elongate seta on either side.

Legs: Very narrow and elongate, densely pilose. Metacoxa > 5 x as long as wide. Tarsi densely pilose on upper and lower surfaces. 4th tarsomeres widened and deeply cleft, densely pilose on lower surface. Tarsal claws very small. Male protarsus not widened and squamose on lower surface, similar to that of female.

Male genitalia: Genital ring fairly narrow, slightly asymmetric, with wide base and rounded apex. Aedeagus rather elongate, straight, little widened in middle, with slightly convex lower surface. Apex depressed, at tip widely more or less rounded. Orificium elongate, situated in middle of upper surface, dorsally on either side with a narrow, elongate rod. Internal sac with some folds and one or two narrow, curved sclerites at bottom in middle of the left side. Parameres moderately large, very dissimilar, right one short, both asetose.

Female gonocoxites): Gonocoxite 1 elongate, with c. 6 extremely elongate setae at the upper ventral rim. Gonocoxite 2 falciform, without any setae. Also the lateral plate at its upper median rim with one or two extremely elongate setae.

REMARKS

The body shape and, in particular, the presence of additional erect setae on the scapus of the antenna suggest a fairly close relationship of *Typhlozuphium* with the genus *Parazuphium*, particularly to the depigmented, small-eyed species of the subgenus *Austrozuphium*. Several character states of the external morphology, e.g. shape and setosity of the clypeus, shape of the labrum, total loss of the eyes, shape of the prothorax, loss of the marginal prothoracic setae, shape of the apex of the elytra, etc., however, demonstrate that it is a well separated genus that in many respects is apomorphic as compared with *Parazuphium*. The aedeagus, however, in its shape and structure, seems to be plesiomorphic, at least when compared with the recorded aedeagi of the species of *Austrozuphium*. Therefore, *Typhlozuphium* could be well related to *Parazuphium*, but may have separated from the *Parazuphium* stock very basally.

ETYMOLOGY

The name refers to the total absence of eyes. The generic name is considered to be neuter.

Typhlozuphium humicolum **sp. nov.**

Figures 2, 5, 7

http://www.zoobank.org/urn:lsid:zoobank.org:act:CA6D4BC1-386C-45C3-80CD-78EA5F94DD25

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , 'W.A.: Mining Area C, c. 93 km NW. Newman 22°54′08.90″S 118°58′53.10″E (WGS 84) 09 Apr. 2010 M.K.Curran, J.S.Cocking (PSD0181R) Trog scrape, 49 m' (WAM E88564).

Paratypes

Australia: ***Western Australia:*** 1 , 'W.A.: Mining Area C, c. 95 km NW. Newman 22°53′55.80″S 118°57′57.40″E (WGS 84) 25 Jun. 2010 M.K. Curran, G.B. Pearson (PSC0889R) Trog scrape' (WAM E84011); 1 , 'W.A.: Mining Area C, c. 87 km NW. Newman 22°55′33.10″S 119°02′06.70″E (WGS 84) 08 Dec. 2007 J.S. Cocking, M.D. Scanion (GA0165R) Trog scrape, 55 m' (CBM); 1 , 'W.A.: Jinidi, c. 65 km NW. Newman 22°58′22.80″S 119°15′32.40″E (WGS 84) 01 Sep. 2011 D.C. Main, J.W. Quartermaine (JIN0109R) Trog scrape, 40 m' (WAM E84008).

DIAGNOSIS

Yellow, blind, narrow and elongate species with elongate, posteriad little widened, almost elliptical head, narrow and elongate, and dorsally slightly convex elytra; distinguished from *T. longipenne* sp. nov. by slightly shorter, apicad slightly widened elytra, slightly shorter antenna, and longer, wider, rather spoon-shaped, very depressed apex of the aedeagus.

DESCRIPTION

Measurements: Length: 4.2–4.3 mm; width: 1.2 mm. Ratio length/width of head: 1.45–1.48; ratio width/length of pronotum: 1.38–1.45; ratio width of widest diameter/ width of base of pronotum: 1.71–1.72; ratio width of head/width of pronotum: 1.06–1.07; ratio length/width of elytra: 2.06–2.07; ratio length/width of scapus: 6.0; ratio length/width of 6th antennomere: 4.0; ratio length/width of metatibia: 5.2–5.3.

Colour: Upper and lower surfaces, palpi, antenna, and legs pale yellow.

Head (Figure 2): Elongate, slightly wider than pronotum, posteriad little widened, about elliptical, widely rounded towards neck. Upper surface rather convex. Eye absent. Frons with a very short, shallow, impression on either side just behind the clypeal suture. Neck short, extremely narrow, separated by a deep furrow. Clypeus small, apical margin convex, trisetose, i.e. with a slightly shorter seta in middle, lateral setae elongate. Labrum deeply concave at apex, 6-setose, the lateral seta longer than the median ones. Mandibles comparatively elongate, wide, at apex suddenly incurved, lateral margin near base with several elongate setae. Palpi rather narrow and elongate, apical palpomeres slightly widened apicad, palpi densely pilose; the basal palpomere of the maxillary palpus rather hirsute, the basal palpomere of the labial palpus at apex with several elongate setae. Mentum with a quadrate tooth, 4-setose behind the tooth. Labium short, glossa wide at apex, paraglossae apparently fused to glossa, at apex apparently 5-setose. Lacinia elongate, median margin with many elongate, stout setae. Galea narrow and elongate, impilose. Antenna very elongate, scapus longer than diameter of head, with one elongate seta near apex and several very short, erect setae within the fairly dense, depressed pilosity; median antennomeres c. 4 x as long as wide, with very dense, adpressed, very short pilosity. One supraorbital seta present, situated at apical third of head. Surface of head sparsely punctate and pilose, pilosity on surface short and inclined anteriad, laterally longer. Microreticulation fine and superficial, about isodiametric.

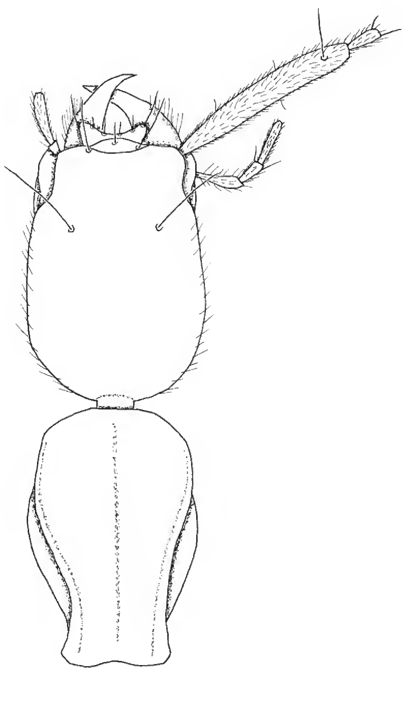

FIGURE 2 Head and pronotum: 1, *Typhlozuphium humicolum* sp. nov. Scale bars = 1 mm.

Prothorax (Figure 2): Rather narrow and elongate, much longer than wide, cordiform, widest at or slightly in front of middle. Apex rather wide, in middle straight, laterally markedly oblique; apical angles obtusely rounded. Lateral margin in apical half slightly oblique and convex, in basal half concave, near base straight. Basal angles slightly removed from base, very slightly triangularly produced. Base rather narrow, in middle slightly concave. Lateral margin slightly carinate, marginal explanation in apical half narrow, very shallow, in basal half slightly wider and deeper. Both, apex and base not margined. Disk rather depressed but uneven, in apical half slightly convex, in basal half slightly impressed. Median line fine, inconspicuous, slightly impressed, almost attaining apex and base. No transverse sulci visible. Basal grooves shallow, narrow, rather elongate. In middle of pronotum proepisternum well visible from above, wide and convex, producing the widest diameter of pronotum. No marginal setae or punctures visible. Surface with dense, coarse, transverse furrows, interrupted by rather dense punctures, with fairly dense, short, declined pilosity. Microreticulation extremely fine and superficial, composed of more or less isodiametric meshes.

Elytra: Elongate and almost parallel-sided; dorsal surface convex but depressed on disk. Humerus oblique. Lateral margins straight. Apex very oblique, not sinuate, not incurved at suture, narrowly marginate; external apical angles widely rounded. At least two median striae just perceptible though barely impressed, median intervals in basal half very slightly raised. No discal punctures and setae visible. Lateral marginal setae extremely elongate, composed of two groups: 4 setae behind humerus, 2 setae near external apical angle. Surface with dense and rasp-like punctation. Pilosity dense, fairly elongate, declined posteriad. Microreticulation distinct, isodiametric. Surface rather dull. Metathoracic wings completely reduced.

Lower surface: Moderately densely punctate and pilose. Pilosity rather elongate, on head and prothorax inclined anteriad, on abdomen inclined posteriad. Metepisternum short, little longer than wide at apex.

1st visible abdominal sternite very elongate, almost as long behind metacoxa as the three following sternites. Terminal sternite in both sexes with one elongate seta on either side.

Legs: Very narrow and elongate, densely pilose. Metacoxa > 5 x as long as wide. Tarsi densely pilose on upper and lower surfaces. 4th tarsomeres widened and deeply cleft, densely pilose on lower surface. Tarsal claws very small. Male protarsus not widened and squamose on lower surface, similar to that of female.

Male genitalia (Figure 5): Genital ring fairly narrow, slightly asymmetric, with wide base and rounded apex. Aedeagus rather elongate, straight, little widened in middle, with slightly convex lower surface. Apex markedly depressed, wide and spoon-shaped, at tip widely rounded. Orificium elongate, situated in middle of upper surface, dorsally on either side with a narrow, elongate rod. Internal sac with some folds and a narrow, curved sclerite at bottom in middle of the left side. Parameres moderately large, very dissimilar, right one very short, both asetose.

Female gonocoxites (Figure 7): Gonocoxite 1 elongate, with c. 6 extremely elongate setae at the upper ventral rim. Gonocoxite 2 falciform, without any setae. Also the lateral plate at its upper median rim with one or two extremely elongate setae.

Variation: Slight variation noted in relative length of prothorax.

REMARKS

The specimens were sampled by 'trog scrape' as discussed above under 'Collecting method', between 40 m and 55 m below the surface.

DISTRIBUTION

All specimens were collected in an area north-west of Newman, in the Pilbara region of north-western Western Australia.

ETYMOLOGY

The name refers to the occurrence of this species in the soil.

Typhlozuphium longipenne **sp. nov.**

Figures 3, 6

http://www.zoobank.org/urn:lsid:zoobank.org:act:DCC32D29-4318-44C9-80E8-3AD242EF0729

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , 'WA: Mining Area C c. 95 km SE Wittenoom 22°54′34.93″S 118°56′34.08″E (WGS 84) 09 November 2013 S.R. Bennett, J.W. Quartermaine (PSB0107R) Trog scrape, 60 m' (WAM E88465).

DIAGNOSIS

Yellow, blind. narrow and elongate species with elongate, posteriad little widened, almost elliptical head, narrow and elongate, and dorsally slightly convex elytra; distinguished from *T. humicolum* sp. nov. by longer and absolutely parallel-sided elytra, slightly longer antenna, and shorter, narrower, about triangular, less depressed apex of the aedeagus.

DESCRIPTION

Measurements: Length: 4.3 mm; width: 1.15 mm. Ratio length/width of head: 1.51; ratio width/length of pronotum: 1.45; ratio width of widest diameter/width of base of pronotum: 1.78; ratio width of head/width of pronotum: 1.06; ratio length/width of elytra: 2.18; ratio length/width of scapus: 6.5; ratio length/width of 6th antennomere: 4.4; ratio length/width of metatibia: 5.4.

Colour: Upper and lower surfaces, palpi, antenna, and legs pale yellow.

Head (Figure 3): Elongate, slightly wider than pronotum, posteriad barely widened, about elliptical, widely rounded towards neck. Upper surface rather convex. Eye absent. Frons with a very short, shallow, impression on either side just behind the clypeal suture. Neck short, extremely narrow, separated by a deep furrow. Clypeus small, apical margin convex, trisetose, i.e. with a slightly shorter seta in middle, lateral setae elongate. Labrum deeply concave at apex, 6-setose, the lateral seta longer than the median ones.

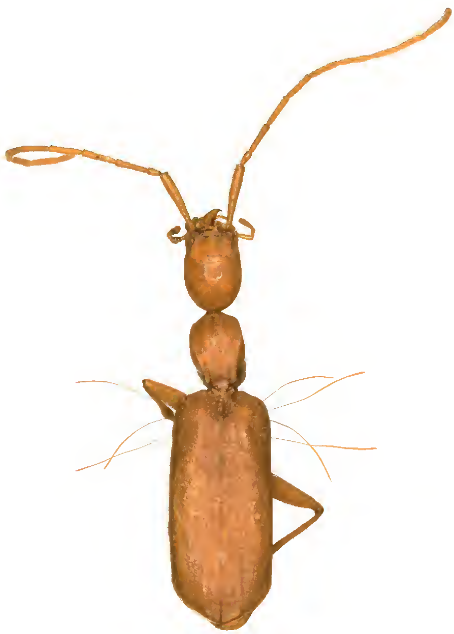

FIGURE 3 *Typhlozuphium longipenne* sp. nov., habitus. Body length: 4.3 mm.

Mandibles comparatively elongate, wide, at apex suddenly incurved, lateral margin near base with several elongate setae. Palpi rather narrow and elongate, apical palpomeres slightly widened apicad, palpi densely pilose; the basal palpomere of the maxillary palpus rather hirsute, the basal palpomere of the labial palpus at apex with several elongate setae. Mentum with a quadrate tooth, 4-setose behind the tooth. Labium short, glossa wide at apex, paraglossae apparently fused to glossa, at apex apparently 5-setose. Lacinia elongate, median margin with many elongate, stout setae. Galea narrow and elongate, impilose. Antenna very elongate, scapus longer than diameter of head, with one elongate seta near apex and several very short, erect setae within the fairly dense, depressed pilosity; median antennomeres > 4 x as long as wide, with very dense, adpressed, very short pilosity. One supraorbital seta present, situated at apical third of head. Surface of head sparsely punctate and pilose, pilosity on surface short and inclined anteriad, laterally longer. Microreticulation fine and superficial, about isodiametric.

Prothorax (Figure 3): Rather narrow and elongate, much longer than wide, cordiform, widest slightly in front of middle. Apex rather wide, in middle straight, laterally markedly oblique; apical angles obtusely rounded. Lateral margin in apical half slightly oblique and convex, in basal half concave, near base straight. Basal angles slightly removed from base, very slightly triangularly produced. Base rather narrow, in middle slightly concave. Lateral margin slightly carinate, marginal explanation in apical half narrow, very shallow, in basal half slightly wider and deeper. Both, apex and base not margined. Disk rather depressed but uneven, in apical half slightly convex, in basal half slightly impressed. Median line fine, inconspicuous, slightly impressed, almost attaining apex and base. No transverse sulci visible. Basal grooves shallow, narrow, rather elongate. In middle of pronotum proepisternum well visible from above, wide and convex, producing the widest diameter of pronotum. No marginal setae or punctures visible. Surface with dense, coarse, transverse furrows, interrupted by rather dense punctures, with fairly dense, short, declined pilosity. Microreticulation extremely fine and superficial, composed of more or less isodiametric meshes.

Elytra (Figure 3): Very elongate, parallel-sided; dorsal surface convex but depressed on disk. Humerus oblique. Lateral margins straight. Apex very oblique, not sinuate, not incurved at suture, narrowly marginate; external apical angles widely rounded. Two median striae just perceptible though barely impressed, median intervals in basal half very slightly raised. No discal punctures

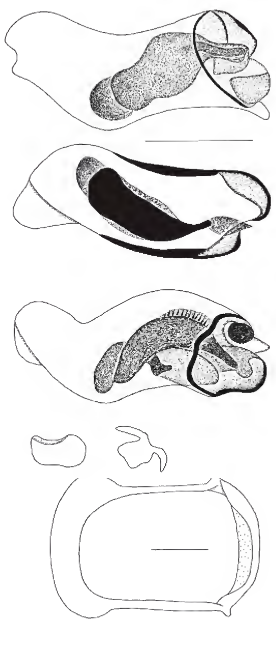

FIGURE 4 Male aedeagus, left side, lower surface, upper surface, parameres, genital ring of *Parazuphium pilbarae* sp. nov. Scale bars = 0.25 mm.

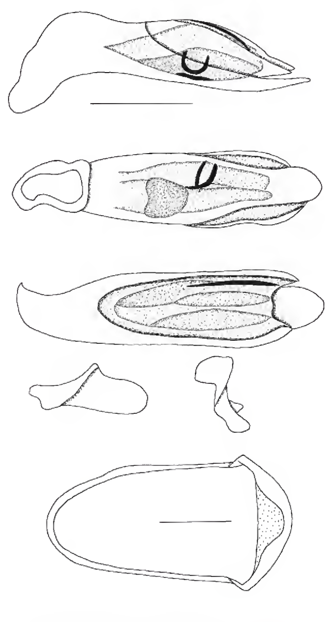

FIGURE 5 Male aedeagus, left side, lower surface, upper surface, parameres, genital ring of *Typhlozuphium humicolum* sp. nov. Scale bars = 0.25 mm.

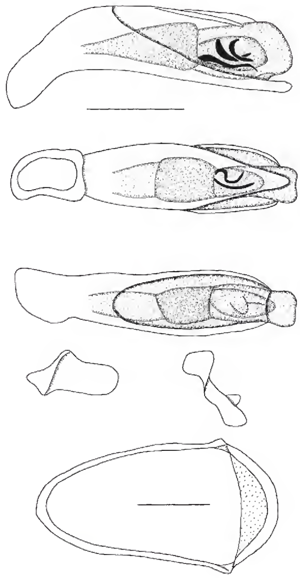

FIGURE 6 Male aedeagus, left side, lower surface, upper surface, parameres, genital ring of *Typhlozuphium longipenne* sp. nov. Scale bars = 0.25 mm.

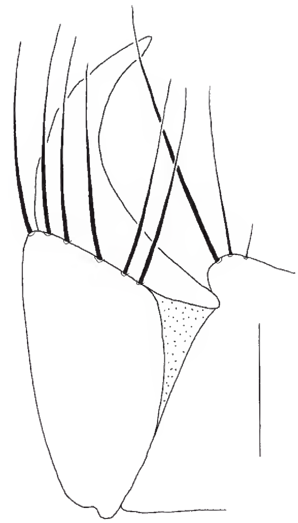

FIGURE 7 *Typhlozuphium humicolum* sp. nov., female gonocoxites and lateral plate. Scale bar = 0.1 mm.

and setae visible. Lateral marginal setae extremely elongate, composed of two groups: 4 setae behind humerus, 2 setae near external apical angle. Surface with dense and rasp-like punctation. Pilosity dense, fairly elongate, declined posteriad. Microreticulation distinct, isodiametric. Surface rather dull. Metathoracic wings completely reduced.

Lower surface: Moderately densely punctate and pilose. Pilosity rather elongate, on head and prothorax inclined anteriad, on abdomen inclined posteriad. Metepisternum short, little longer than wide at apex. 1st visible abdominal sternite very elongate, almost as long behind metacoxa as the three following sternites. Terminal sternite in male with one elongate seta on either side.

Legs: Very narrow and elongate, densely pilose. Metacoxa > 5 x as long as wide. Tarsi densely pilose on upper and lower surfaces. 4th tarsomeres widened and deeply cleft, densely pilose on lower surface. Tarsal claws very small. Male protarsus not widened and squamose on lower surface.

Male genitalia (Figure 6): Genital ring fairly narrow, slightly asymmetric, with wide base and rounded apex. Aedeagus rather elongate, straight, little widened in middle, with slightly convex lower surface. Apex moderately depressed, rather narrow, triangular, with obtuse tip. Orificium elongate, situated in middle of upper surface, dorsally on either side with a narrow, elongate rod. Internal sac with some folds and two narrow, curved sclerites at bottom in middle. Parameres moderately large, very dissimilar, right one very short, both asetose.

Female gonocoxites: Unknown.

Variation: Unknown.

REMARKS

The holotype was sampled by 'trog scrape' as discussed above under 'Collecting method', at 60 m below the surface.

DISTRIBUTION

This species is known only from the vicinity of Wittenoom, in the Pilbara reigon of north-western Western Australia.

ETYMOLOGY

The name refers to the very elongate, parallel-sided elytra of this species.

REMARKS

The new species and new genus described above demonstrate the insufficient knowledge on the Australian Zuphiini. Application of new, elaborate

collecting methods, as mentioned in above, can in the future bring to light new and interesting soil inhabiting or subterraneous species and might further raise the number of zuphiine species in Australia. This sampling methods should be conducted more systematically and in other parts of Australia. We are however, already much obliged to the collectors for their novel approach which illustrates an excellent example for future collecting.

Both new species of the genus *Typhlozuphium* are very closely related and differ only slightly in body shape, length of antenna, and in shape and structure of the aedeagus. However, the differences suggest that species of this genus possess quite restricted ranges. This is not too surprising for blind, flightless, and subterranean species. Therefore, we can suppose that additional species might occur in other parts of the Pilbara. Very restricted ranges of most subterranean arthropod species sampled during the Pilbara survey were also suggested by Halse and Pearson (2014) in their report on that survey.

The high grade of similarity in both species of *Typhlozuphium* suggests a rather recent origin, *resp.* separation of both species, which still are very closely related. Certainly, it is not yet possible to speculate about the phylogenetic relationships of the Pilbara subterranean zuphiines or about their biogeographic history, but perhaps future surveys might reveal very interesting results for both questions.

Few blind zuphiine species thus far have been recorded from Australia. The two species (and genera) described by Moore (1995) from caves in the Nullarbor Plain are true cave inhabiting species which are even more adapted to subterranean life than *Typhlozuphium*, have lost even more character states of epigean Zuphiines and have acquired more distinctive attributes. For *Speothalpius grayi* Moore, therefore, its affiliation to Zuphiini even remains unsettled.

ACKNOWLEDGEMENTS

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New species of subterranean silverfish (Zygentoma: Nicoletiidae: Atelurinae) from Western Australia's semi-arid Pilbara region

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ABSTRACT – Three new species of the usually inquiline Atopatelurini, collected deep within iron-ore formations via mining bore holes, are described. Two species, *Dodecastyla crypta* sp. nov. and *D. rima* sp. nov. are placed in the Chilean genus *Dodecastyla* Paclt although certain ambiguities still exist regarding this genus. *Troglotheus* gen. nov. is erected for inclusion of *T. bifurcus* sp. nov. due to the absence of dorsal tergal chaetotaxy. Habitat data and possible host associations are discussed.

KEYWORDS: hypogean, troglophile, inquiline, iron-ore formations

INTRODUCTION

Silverfish of the family Nicoletiidae are well known from subterranean habitats. With the exception of the Atelurinae, the members of this family are elongate, primitively eyeless and generally lack pigmentation. While about half of all described non-atelurin species have been found in soil related habitats (in humus or under rocks), the remainder have been collected from within limestone caves (e.g. Mendes 1994) or from lava tubes (e.g. Espinasa and Espinasa Closas 2006, Smith 2006). Cave-adapted forms are often quite spindly with longer legs and sensory appendages. In recent years, biological survey work for mining companies in Western Australia has seen the sampling of fauna deep within various rock strata via drilled geological exploration holes. This has revealed a rich and highly adapted subterranean fauna (e.g. Guzik et al. 2010, Halse and Pearson 2014) consisting mostly of short range endemic species, restricted sometimes to a single outcrop. Smith et al. (2012) described silverfish species of the subfamily Subnicoletiinae sampled via such exploration holes in banded iron formations from the northern part of the Pilbara region in Western Australia.

The Atelurinae, once considered as an independent family (e.g. Watson 1970) but now treated as a subfamily within the Nicoletiidae, are considered as specialised for a living as inquilines or 'tolerated guests' of ants or termites. Many species, especially those hosted by termites, display striking morphological adaptations. These include a much more convex dorsum, a round or tear-drop shape and reduced appendage lengths, especially of the terminal filaments, and in extreme cases highly modified terminalia, particularly in the males. Other atelurin species seem to be quite flexible in their host associations and do not display the more extreme morphological adaptations. They can often be found in soil without any obvious host although they are usually not regarded as hypogean silverfish. On two occasions, however, one of us (Smith) has observed unidentified atelurins travelling with lines of ants deep within caves (Cape Range, WA and Undara, Qld) and on another occasion (also at Undara) high density populations (c. 30/m^2) of *Pseudogastrotheus* sp. were sampled from the muddy floor of a lava tube without any obvious ant presence. This paper describes three new species of Atelurinae that have been collected from deep within rock formations via exploratory drill holes in the central part of the semi-arid Pilbara region of Western Australia.

The subfamily Atelurinae is quite diverse with some 70 described genera, many of which are monotypic. Mendes (2012) divides the subfamily into five tribes, placing all described Australian species within the Atopatelurini, a tribe characterised by the absence of scales on the head, the presence of a fovea but the lack of antennal apophyses on the pedicel of mature males, well developed molar regions of the mandibles, a galea with just one apical conule, legs with lyriform spines, the lack of specialised armature on the median dorsal appendage of mature males, pseudovesicles on urosternite VII and the presence of 1+1 vesicles on urosternite VI which have a medial tuft of well developed setae. The tribe has a wide distribution with species described from Africa and the Middle East, South Asia, Indonesia, Papua-New

http://www.zoobank.org/urn:lsid:zoobank.org:pub:FC516109-8064-4C28-99B0-E123C49599CD

Guinea, New Zealand, South America and Australia. Hosts include termites of the families Mastotermitidae, Termitidae and Rhinotermitidae as well as ants (Formicidae).

The Australian atelurin fauna is not well documented with only nine species having been described, despite many more being represented in various entomological collections. References to the genus *Atelurodes* Silvestri, 1916 in Australia (e.g. Smith 1998a), following the lead of Wygodzinsky (1963), are incorrect. *Atelura similata* Silvestri, 1908 with five pairs of abdominal stylets, requires redescription and will probably be placed within a new genus near *Pseudogastrotheus* Mendes, 2003 (with only four pairs of stylets).

This paper describes three new species from the Pilbara with six pairs of stylets, which along with other characters, appears to place them in or near the genus *Dodecastyla* Paclt, 1974 erected for the Chilean species *Lepismina bifida* Schäffer, 1897. Two of the three species will be placed, at least provisionally, in *Dodecastyla* Paclt. A new genus will be erected for the third species owing to its very different head and dorsal chaetotaxy. This position may need to be revised when more information becomes available on the chaetotaxy of the head and the presence of pulvilli in *Dodecastyla bifida*.

FIGURE 1 *Australiatelura tasmanica* (Silvestri, 1949): scanning electron micrograph of abiesiform macrochaeta with small setula to the upper right of it, above a typical scale insertion.

MATERIALS AND METHODS

ABBREVIATIONS

I–X	abdominal segments from anterior to posterior are numbered with roman numerals
HW	head width (always in millimetres)
H+B	head and body length
juv.	juvenile
L/W	length to width ratio
My	million years
N, S, E, W	compass directions north, south, east, west (often in combination)
PI, PII, PIII	prothoracic, mesothoracic and metathoracic legs respectively
PVC	polyvinyl chloride (plastic)

TERMINOLOGY

Left and right are used in respect to the animal's left or right side when viewed from above with the head forward.

A new term will also be introduced in this paper for a type of tergal seta or macrochaeta common within the Atopatelurini. The shape of the individual macrochaetae can be quite significant for the Zygentoma and the term 'apically bifid' is used to describe a wide variety of forms, from quite delicate splits at the very apex, through the strong lyriform spines found on the legs of many atelurin species such as *Atopatelura furcifera* Silvestri, 1908 or *Ausallatelura ordoarmata* Smith, 2007 to the antennal macrochaetae of *Crypturelloides mindeni* Smith and Veera Singham, 2011, which are quite long yet bifurcated for up to ⅔ of their length. Several genera, including *Australiatelura* Mendes, 1995 and *Dodecastyla* display flattened bifurcated setae along the posterior margins of the thoracic and abdominal tergites (Figure 1). In his redescription of *Dodecastyla bifida* (as *Grassiella bifida*) Silvestri (1905) describes these macrochaetae as short deeply apically incised scales 'Thorax et abdomen tergites squamis brevibus, latiusculis in apice sat profunde incisis' and for *Australiatelura tasmanica* (Silvestri, 1949) describes them as a transverse row of short, robust, apically incised setae 'serie transversali setarum robustarum brevium, in apice incisarum'. Mendes (1986) describes these as spathulate setae with a profound apical incision 'sedas espatuladas e com incisão apical profunda'. Stach (1935) commented that these setae resembled fir needles 'Diese Borsten errinern sehr an die Nadeln einer Tanne; die sind also zugeflacht, an der Spitze seicht gespalten und haben einer Mittelrippe'. The Latin word for fir is 'abies' which also forms the generic name for trees such as the Silver Fir (*Abies alba* Miller, 1768), which have needles that bear some resemblence to these flattened setae. Taking the lead from Stach, we would like to propose the use of the term 'abiesiform' to describe this distinct form of macrochaeta while recognising that there will be a degree of transition between the various types of macrochaetae.

STUDY AREA

The Pilbara region in north-western Australian has been emergent for up to 3.5 billion years (Buick et al. 1995) and has experienced a range of climates. At the end of the Oligocene, the climate was temperate and the region supported small patches of rainforest. Aridity increased in the mid-Miocene (Macphail and Stone 2004, Martin 2006) and it is likely that some ground-dwelling invertebrates began moving underground in the late Miocene or early Pliocene to escape the drying conditions. Although the major elements of the Pilbara's current climate came into place about 0.5 My ago, aridity has continued to increase (Martin 2006).

The Pilbara now has a semi-arid climate and mostly receives monsoonal rainfall as infrequent events during hot summers, although there is significant winter rain some years, especially in the southern Pilbara. Average annual rainfall is mostly 250–350 mm across the Pilbara and average temperatures in the hottest summer month (January) range from 36°C near the coast to 41°C inland (http://www.bom.gov.au/). Winters are warm and usually dry and annual pan evaporation is approximately 3500 mm (Luke et al. 2003).

The three species described here were collected from iron ore formations in two parts of the Hamersley Range in the central Pilbara (Packsaddle Range and Valley of the Queens) and from Cape Preston near the Pilbara coast (Figure 2). Vegetation in all three locations is dominated by spinifex grasses (*Triodia* spp.) with occasional eucalypt trees providing a very sparse overstorey. The areas sampled for troglofauna at Packsaddle Range were elevated ridgelines made up primarily of Brockman Iron Formation. Weathered sections of the iron formation at Packsaddle contain extensive fissures and voids to depths of up to 90 m. Depth to groundwater was approximately 70–100 m. At Valley of the Queens, sampling occurred on the valley floor or lower hill slopes, which mostly comprised Detrital Iron Deposit and alluvium/colluvium. The depth to groundwater was 8 m and there were abundant interstitial spaces in the iron deposit and alluvium above the water table. At Cape Preston, sampling occurred in Brockman Iron Formation. The depth to groundwater was 20-30 m.

COLLECTION METHODS

Sampling occurred in holes drilled for geological exploration 1–2 years prior to sampling. The holes contained a short PVC collar extending from about 0.5 m above to 2 m below ground surface to prevent collapse of the drill hole. Holes were 150 mm in diameter and open (uncased) below the collar.

All type material was collected by scraping. This technique consisted of lowering a weighted conical net of made of 150 micron mesh to the bottom of the hole and scraping the net along the bore wall as it was retrieved, with the aim of dislodging troglofauna into the net (Halse and Pearson 2014). After retrieval and removal of as much rock and sediment as possible, the contents of the net were preserved in 100% ethanol. Some additional animals were collected in PVC traps baited with leaf litter and set in the drill holes for eight weeks before retrieval.

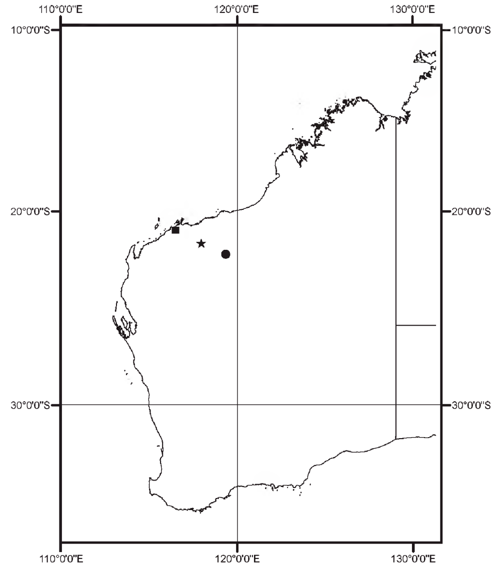


FIGURE 2 Localities of:
■ *Dodecastyla rima* sp. nov.,
● *Dodecastyla crypta* sp. nov.,
★ *Troglotheus bifurcus* sp. nov.

SPECIMEN PREPARATION

After removal of a leg from the specimens which had been stored in 100% ethanol for possible DNA sequencing, the rest of the specimen was placed into 75% ethanol for a few months prior to the descriptive work in order to reduce fragility during handling or dissection. A series of measurements of most specimens was undertaken according to the method described in Smith (1998b). All silverfish specimens collected during this survey have been deposited with the Western Australian Museum, Perth. Unless specified as being mounted on slides, all specimens are stored individually in 80 or 100% ethanol. All specimens listed were examined, however the details required to separate the species are only seen with confidence on slide mounted material. Several male and one female specimen from each area were dissected and mounted onto two slides in Tendeiro solution with head and thorax on one slide and abdomen on the other (see Smith et al. 2012). No problems were encountered with twisting of the macrochaetae in the medium. Considering the fragility of subterranean silverfish, the specimens received were in reasonable condition although most terminal filaments were damaged to some degree, many setae had been lost and several specimens were broken into two pieces. One specimen (WAM E84137), which was already somewhat

damaged on receipt, proved extremely difficult to dissect with sclerites tearing very easily and the tissue not separating from the cuticle. It is assumed that this was a freshly moulted specimen, where the cuticle had not fully hardened at the time it was captured and where the cuticle was still strongly attached to the underlying tissue. However all small subterranean nicoletiids seem to be quite delicate and easily damaged during dissection. Another problem was that a layer of very fine red dust adhered to the cuticle of some specimens, which made interpretation of the various structures more difficult.

SYSTEMATICS

Family Nicoletiidae Escherich, 1905

Nicoletiinae Escherich, 1905: 117.

Subfamily Ateluriinae Remington, 1954

Atelurinae Remington, 1954: 284.

Tribe Atopatelurini Mendes, 2012

Atopatelurini Mendes, 2012: 22.

Genus *Dodecastyla* Paclt, 1974

Lepismina Gervais: sensu Grassi and Rovelli, 1889: 3 (pro parte).

Grassiella Silvestri, 1898: 35 (pro parte).

Atelura von Heyden: Escherich, 1905: 118 (pro parte).

Dodecastyla Paclt, 1974: 545.

TYPE SPECIES

Lepismina bifida Schäffer, 1897, by original designation.

Dodecastyla crypta sp. nov.

Figures 3–46

http://www.zoobank.org/urn:lsid:zoobank.org:act:59E5657C-0A9B-4ABE-BBE7-936B8DA30EEF

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** (HW 0.63), Mining Area C, c. 92 km NW. of Newman, drill hole PSD0149R (22°54'03.60"S, 118°59'34.70"E), 27 June 2010, collected by scraping root mat at about 10 m depth in drill hole which was 90 m deep in total, M.K. Curran, G.B. Pearson (WAM E84156) on two slides.

Paratypes

Australia: ***Western Australia*:** 1 (HW 0.70), same data as holotype (WAM E84157) in alcohol; 1 (HW 0.69), same data as holotype (WAM E84158) on two slides; 1 (HW 0.73), same data as holotype (WAM E84159) in alcohol.

Other material examined in detail but not included in type series

Australia: ***Western Australia*:** 1 (HW not recorded), Mining Area C, c. 95 km of SE. Wittenoom, Deposit F GF0268R (22°56'15.80"S, 118°52'21.50"E), 5 February 2008, trap at 51 m, G.B. Pearson, M.D. Scanlon (WAM E84137) on two microscope slides (head separated from body when received); 1 (HW 0.73), Mining Area C, c. 90 km WNW. of Newman, Deposit A GA0272R (22°56'15.80"S, 118°52'21.50"E), 7 December 2007, scraping 21 m, J.S. Cocking, M.D. Scanlon (WAM E84138) in alcohol; 1 (HW 0.65), Mining Area C, c. 92 km WNW. of Newman, Deposit C GC0108R (22°55'37.40"S, 118°58'28.00"E), 13 January 2008, scraping 24 m, J.S. Cocking, M.D. Scanlon (WAM E84139) in alcohol; 1 (HW 0.70), Mining Area C, c. 94 km WNW. of Newman; Deposit D GD0041R (22°55'47.50"S, 118°57'03.80"E), 11 January 2008, scraping 90 m, J.S. Cocking, M.D. Scanlon (WAM E84140) in alcohol; 1 (HW 0.63), Mining Area C, c. 98 km SSE. Wittenoom, South Flank SF0564R (22°59'42.60"S, 118°50'21.20"E), 18 March 2010, scraping 57 m, J.S. Cocking, D.C. Main (WAM E84141) on two slides (slightly dirty and desiccated); 1 (HW 0.60), Mining Area C, c. 98 km SSE. Wittenoom, South Flank SF0565R (22°59'40.60"S, 118°50'20.50"E), 18 March 2010, scraping 70 m, J.S. Cocking, D.C. Main (WAM E84142) in alcohol (in poor condition); 1 juv. (HW 0.60), same drill hole as previous, 15 June 2010, scraping, M.K. Curran, G.B. Pearson (WAM E84143) in alcohol (in poor condition); 1 (HW 0.65), Mining Area C, c. 91 km WNW. of Newman; South Flank SF0752R (23°00'03.80"S, 118°56'29.80"E), 24 March 2010, scraping 80 m – ants present, M.K. Curran, G.B. Pearson (WAM E84144) in alcohol; 1 (HW 0.60), Mining Area C, c. 96 km WNW. of Newman, Packsaddle P3 PSC0899R (22°54'03.80"S, 118°56'57.70"E), 26 June 2010, scraping – ants present, M.K. Curran, G.B. Pearson (WAM E84145) in alcohol; 1 (HW 0.65), Mining Area C, c. 95 km WNW. of Newman, Packsaddle P3 PSC0874R (22°54'01.90"S, 118°57'35.10"E), 7 April 2010, scraping 59 m – ants present, M.K. Curran, J.S. Cocking (WAM E84146) on two microscope slides; 1 (HW 0.50), same data as previous (WAM E84147) in alcohol; 1 juv. (HW 0.50), same data as previous (WAM E84148) in alcohol; 1 juv. (HW not recorded), same data as previous (WAM E84149) in alcohol; 1 (HW 0.70), Mining Area C, c. 86 km WNW. of Newman, South Flank East SF0149R (23°00'38.70"S, 118°59'39.50"E), 26 May 2010, scraping 40 m, J.S. Cocking, D.C. Main (WAM E84150) in alcohol; 1 juv. (HW 0.48), same data as previous (WAM E84151) in alcohol; 1 juv. (HW 0.50), Mining Area C, c. 86 km WNW. of Newman, Deposit R GR0083R (22°58'19.00"S, 119°01'14.10"E), 21 February 2010, stygofauna net 74 m – ants present, G.B. Pearson, D.C. Main (WAM E84152) in alcohol; 1 (HW 0.50), same data as previous (WAM E84153) on two slides; 1 (HW 0.63), Mining Area C, c. 93 km NW. of Newman, Packsaddle P4 PSD0115R (22°54'07.10"S, 118°59'19.20"E), 27 June 2010, scraping – ants present, M.K. Curran, G.B. Pearson (WAM E84154) in alcohol; 1 (HW 0.63), Mining Area C, c. 93 km NW. of Newman, Packsaddle P4 PSD0147R (22°54'05.40"S, 118°59'22.70"E), 27 June 2010, scraping, M.K. Curran, G.B. Pearson (WAM E84155) in

alcohol; 1 (HW 0.80), Mining Area C, c. 95 km SE. of Wittenoom, GBRS0180 (22°55'32.52"S, 118°52'34.64"E), 7 November 2013, scraping 12 m, S.R. Bennett, J.W. Quartermaine (WAM E84136) on two slides; 1 (HW 0.70), Mining Area C, c. 95 km SE. of Wittenoom, GF0268R (22°56'15.80"S, 118°52'21.50"E), 6 December 2007, scraping 51 m, J.S. Cocking, M.D. Scanlon (WAM E84135) on two slides.

DIAGNOSIS

This species is distinguished from *Dodecastyla bifida* by its much longer antennae (20–21 articles vs 13–14) and by the simple lateral macrochaetae of its urotergites (vs abiesiform macrochaetae in *D. bifida* if the illustrations in Silvestri (1905) are correct).

DESCRIPTION

Male

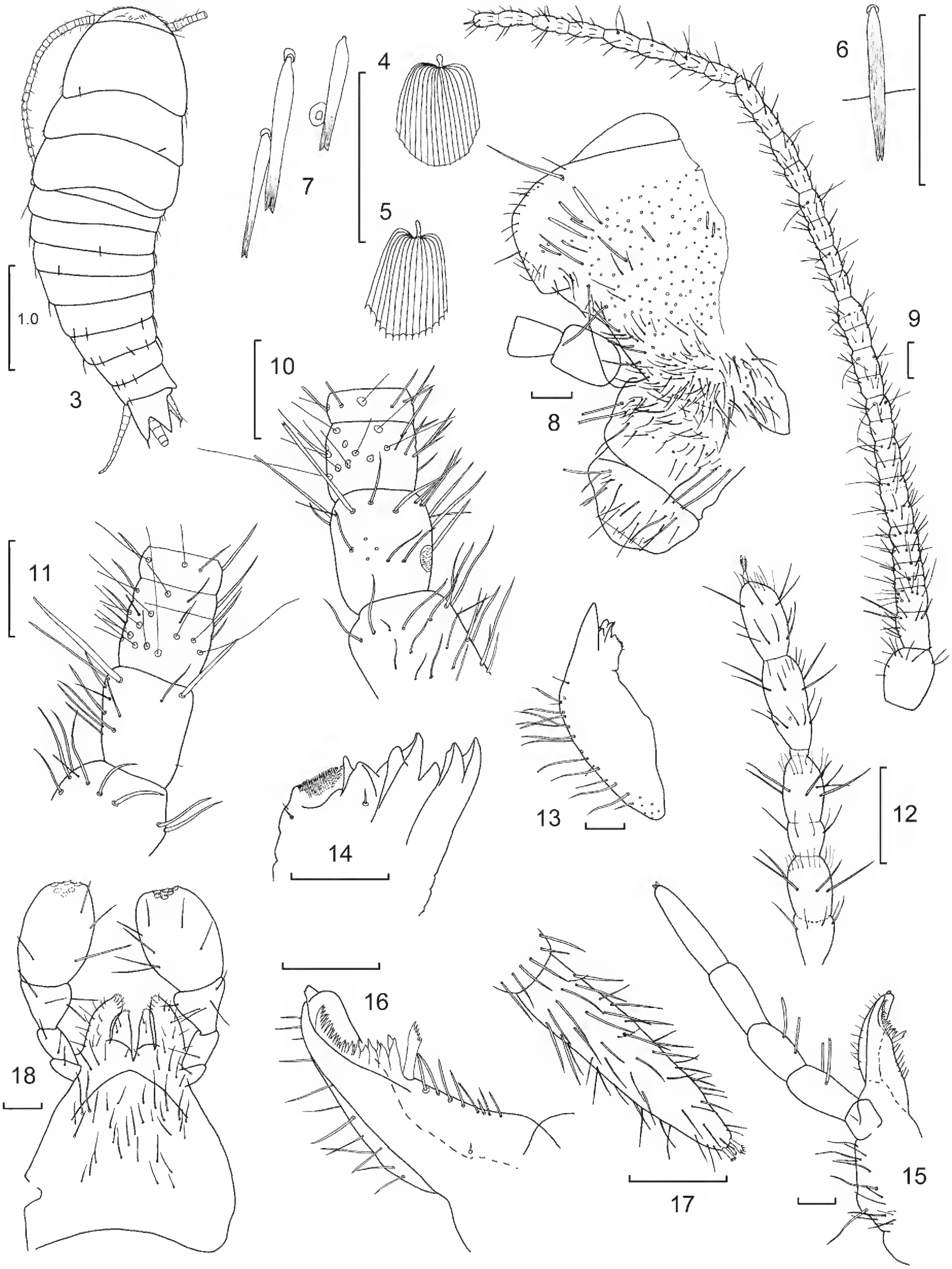
Body length: up to about 4.4 mm (WAM E84136); thorax length: 1.5 mm (or 0.35–0.38 H+B); thorax width: 1.33 mm, widest at meso or metathorax; antennae about 0.6 times H+B, cerci about 0.2 times H+B extending beyond the apex of urotergite X by a little less than the length of urotergite X, median dorsal appendage broken in all specimens but almost complete in specimen E84157 being about twice the length of the cerci. Body ateluroid (Figure 3). Scales in alcohol preserved specimens without colour and ovoid, rays on dorsal scales (Figure 4) not or only just protruding beyond the margin of the scale, those on the scales of the ventral surface protruding slightly (Figure 5). Macrochaetae mostly simple or slightly apically bifurcate, tergites with a submarginal row of abiesiform macrochaetae (Figure 6), posterior setae of head modified to flattened, longitudinally striated and apically forked, appearing somewhat similar to the dorsal abiesiform setae of the body but tapering along their length (Figure 7).

Head as in Figure 8, wider than long, without scales but with numerous setae, some simple and others apically bifurcate, those nearer to the posterior margin flattened, tapering scale-like setae. Antennae (Figure 9) long with 20 to 21 articles (in WAM E84158), pedicel about half as long as the scape, with fovea consisting of a small circular field of short pointed setulae on the inner ventral face, article three with 10 trichobothria (Figures 10 and 11), although with an often indistinct separation between articles three and four it can appear that there are 12 trichobothria; article four short, articles five to eight becoming longer, articles subdivided from article eight or nine, last article with feathered papilla typical of the Atelurinae (Figure 12), articles four to 14 or 16 with two trichobothria, remaining articles with only one trichobothria, when articles subdivided the trichobothria are only present on the distal subarticle. Mandibles strong with row of macrochaetae along the outer face (Figure 13), and well developed incisor and molar regions (Figure 14). Maxilla (Figures 15 and 16), lacinia with single strong tooth, several lamellate processes that merge into a pectinate process that is slightly shorter than the tooth, seven setae on inner margin proximal to lamellate processes, galea about same length as lacinia with single prominent apical papilla; apical article of maxillary palp (Figure 17) 2.1–2.4 times longer than wide and 1.4–1.5 times longer than penultimate article, with three apical papillae, second and third article with some stronger setae subapically. Labium (Figure 18) longer than wide; labial palp somewhat elongated, apical article ovoid shape (Figure 19), about 1.2–1.6 times longer than wide with usual 3+2+1 apical papillae.

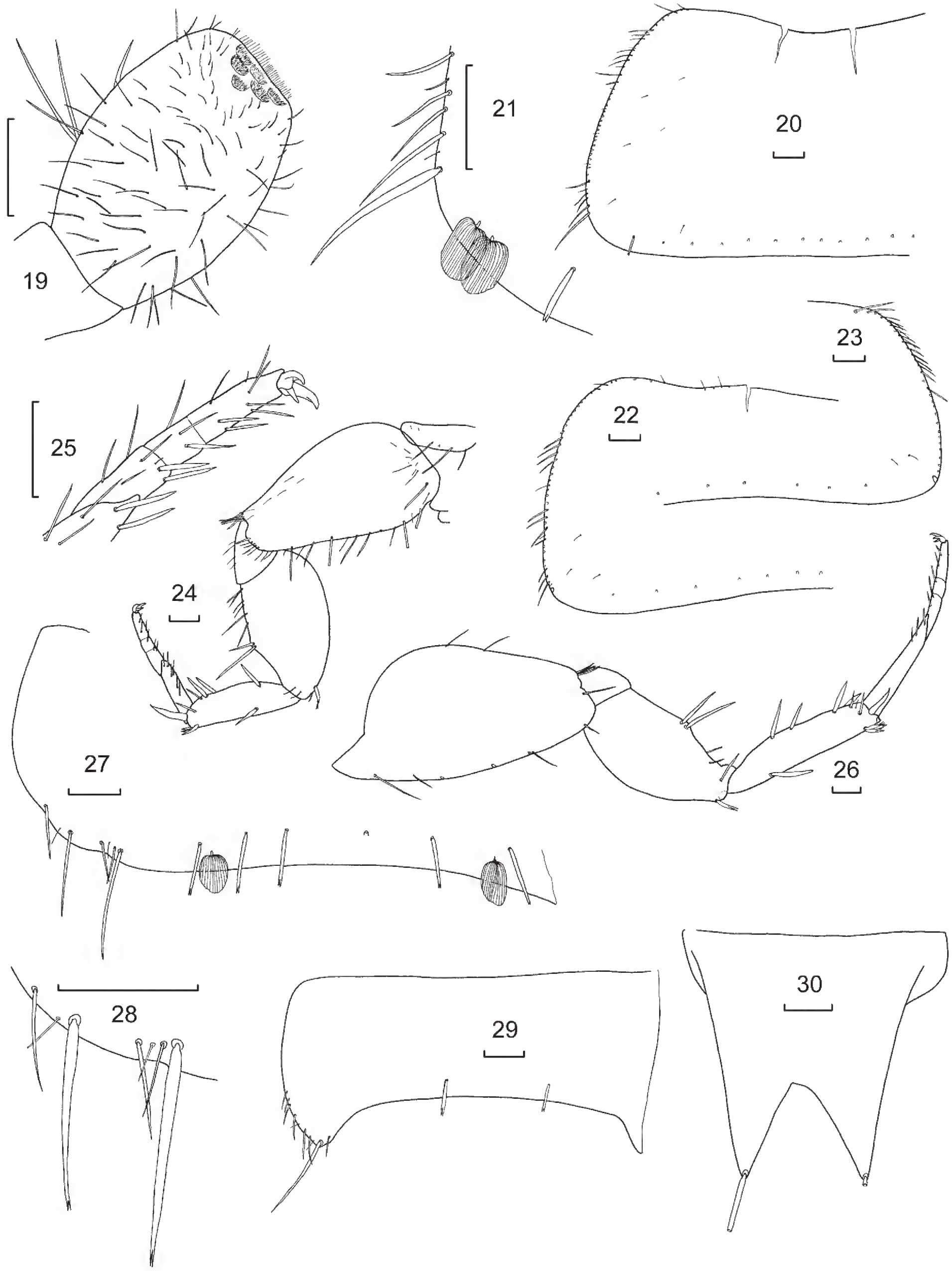
Thoracic nota (Figures 20–23) with posterior border straight to slightly concave, lateral margins with small simple setae and a larger macrochaeta in the posterior corner on each side, posterior border with row of subequidistant abiesiform setae set back from margin with ends just surpassing the posterior margin of the nota, several small setulae on disc in lateral quarter of each nota and some placed between the marginal setae. About 17–18 abiesiform macrochaetae on pronotum, about 14–16 on mesonotum and 11–14 on metanotum. In contrast to those of the abdomen, the single preserved abiesiform seta of the nota is only about as long as the adjacent scale on the nota.

Legs very long (Figures 24–26), tibia L/W ratio of legs PI 3.8–4.3, PII 3.3–4.3, PIII 3.3–5.7; tarsi L/W ratio PI 8.8–9.0, PII 8.3–12.2, PIII 9.0–12.7. Some scales on all coxae. Transverse row of about three apically bifurcated and one simple macrochaeta across the small sclerite at the base of the coxa of PI. Coxa with some longer thin and four to five longer stronger setae along the outer margin and several stronger setae on the end of the inner margin over the articulation; trochanter short with fine setae; femur with two long macrochaetae on the posterior bulge and another longer seta between these and the trochanter, a single longer lyriform spine subdistally on the outer margin; tibia with four strong macrochaetae on ventral face and posterior margin as well as three strong lyriform spines subapically on the outer margin and a long ventral apical spur; tarsi with four articles, basal article as long as following three articles together, with oblique join to next article, pretarsus with three claws, the medial claw being slightly shorter and straighter; lamellate pulvilli absent.

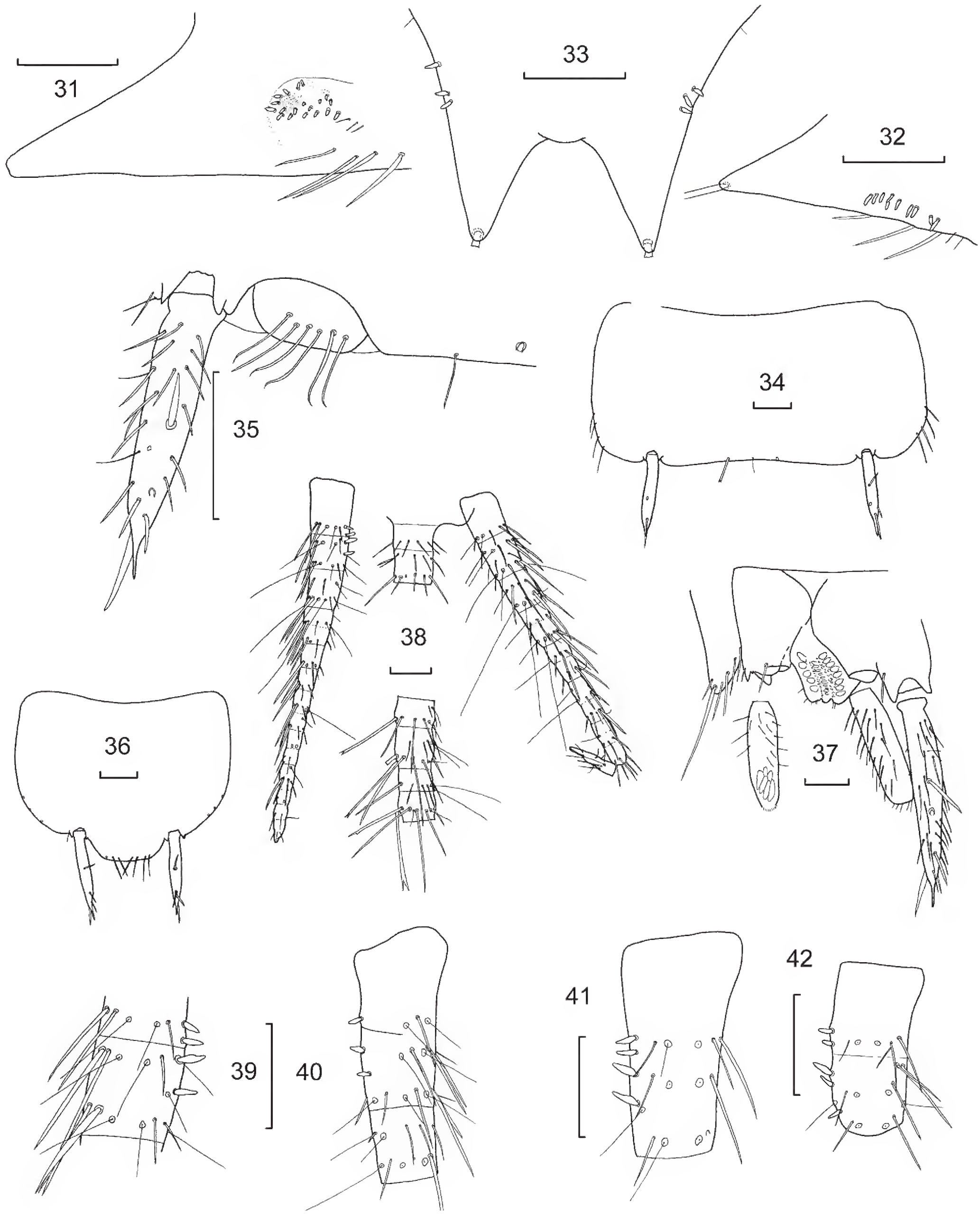
Urotergites become progressively narrower posteriorly; paratergites fold strongly under body with distinct carina at the side of the body; suture between tergite and paratergite often indistinct but tergite easily tears along this line when preparing slide preparations. Much of urotergite I hidden under the metanotum (Figure 3). Urotergites I–IX (Figures 27–29), with submarginal row of sub-evenly spaced abiesiform setae that are about 1.5 times the length of adjacent scales along the posterior margin, decreasing in number posteriorly from 12 on urotergite I to eight on urotergites V and VI, six on urotergites VII and VIII and only two or four (WAM E84157) on urotergite IX. Lateral corners with one longer delicately apically bifurcate seta and then two shorter simple setae at the level of the suture with the paratergites, as well as two simple or delicately apically bifurcate setae on the outer margin (Figure 27). There may be occasional setulae at about the level of the row of abiesiform setae as well as associated with the urotergal chaetotaxy. Urotergite IX (Figure 29) with postero-lateral corner produced backwards with one strong macrochaeta and several smaller seta on each lateral margin. Urotergite X similar in shape for both sexes (Figure 30), posterior corners acute but not strongly elongated, each bearing an apical macrochaeta. Males with small fields of sensory cones present on the underside on



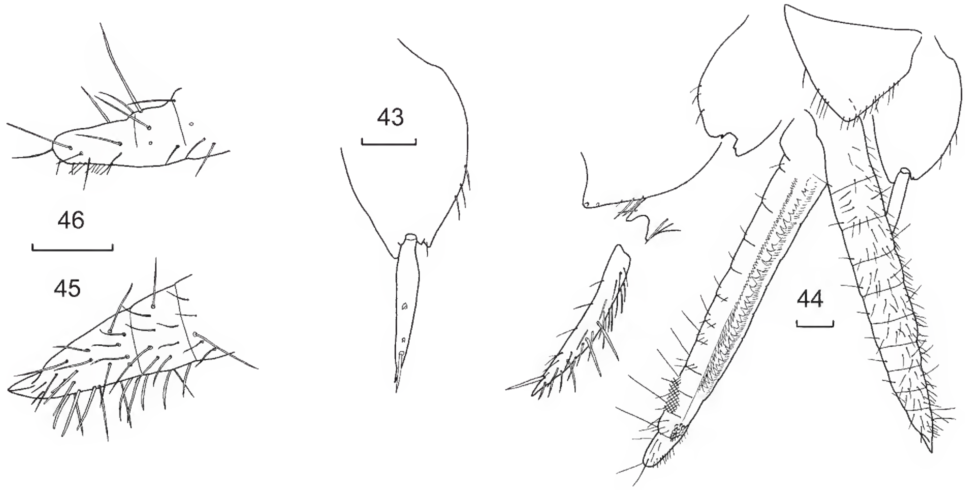
FIGURES 3–18 *Dodecastyla crypta* sp. nov., holotype male (WAM E84156) unless otherwise indicated by specimen number: 3, habitus; 4, dorsal abdominal scale; 5, ventral abdominal scale; 6, abiesiform macrochaeta of urotergite VIII; 7, head setae (WAM E84158); 8, head, right side (WAM E84158); 9, antenna (WAM E84158); 10, antenna, enlargement of four basal articles; 11, idem, (WAM E84158); 12, antenna, enlargement of apical articles (WAM E84158); 13, mandible; 14, idem, enlargement of incisor and molar regions; 15, maxilla (smaller setae omitted from palp); 16, idem, enlargement of apices of lacinia and galea; 17, idem, enlargement of ultimate article of palp; 18, labium (smaller setae omitted from palp). All scale bars = 0.1 mm.



FIGURES 19–30 *Dodecastyla crypta* sp. nov., holotype male (WAM E84156) unless otherwise indicated by specimen number: 19, last article of labial palp; 20, pronotum, left side; 21, idem, detail of posterolateral corner; 22, mesonotum, left side; 23, metanotum, right side; 24; prothoracic leg (smaller setae not shown); 25, idem, last three articles of tarsus; 26 metathoracic leg (smaller setae not shown); 27, urotergite IV, left side; 28, idem, detail of left posterolateral corner; 29, urotergite IX (right paratergite missing); 30, urotergite X (female) (WAM E84158). All scale bars = 0.1 mm.



FIGURES 31–42 *Dodecastyla crypta* sp. nov., holotype male (WAM E84156) unless otherwise indicated by specimen number: 31, underside of urotergite X, left half; 32, idem (WAM E84153); 33, underside of urotergite X (WAM E84137); 34, urosternite V; 35, urosternite VI, detail of right eversible vesicle and stylet; 36, urosternite VIII; 37, urosternite IX, left stylet, parameres and penis as well as right paratergite; 38, cerci and part of median dorsal appendage; 39, basal two articles of right cercus; 40, basal three articles of left cercus (WAM E84137); 41, basal two articles of left cercus (WAM E84136); 42, basal two articles of left cercus (WAM E84153). All scale bars = 0.1 mm.



FIGURES 43–46 *Dodecastyla crypta* sp. nov. paratype female (WAM E84158): 43, right urosternite VIII; 44, genital region showing ovipositor, subgenital plate, stylet IX and outlines of urosternites VIII and IX as well as portion of right paratergite; 45, ovipositor, detail of apex of anterior gonapophysis; 46, idem, detail of apex of posterior gonapophysis. All scale bars = 0.1 mm.

each side adjacent to similar but larger modified setae on the cerci (Figures 31–33). The arrangement of these cones was surprisingly inconsistent, with the cones surrounding a small open, grainy area on the holotype (Figure 31), forming a narrow row in WAM E84153 (Figure 32) and reduced to just three cones on each side in WAM E84137 (Figure 33). The degree of flattening of urotergite X when mounted and the amount of accumulated dust can make interpretation of the arrangement difficult but does not explain the wide variation observed.

Urosternite I glabrous (lost in slide of holotype), urosternites II–VII (Figure 34) with 1+1 submedial apically bifurcate submarginal setae and often a few small marginal setulae and 3-4 small setae on the postero-lateral corners. Urosternite VI also with 1+1 eversible vesicles (Figure 35) each armed with six or seven simple setae in a single but slightly irregular row. Urosternite VII with pseudovesicles. Urosternite VIII of male (Figure 36) strongly convex between the stylets with seven submarginal setae. Six pairs of stylets (on urosternites IV–IX), those on IX almost twice as large as those on the anterior segments, stylets with distinct apical spine and some stronger setae subapically and along the stylet as well as smaller setae (Figures 35 and 37). Urosternite IX in male (Figure 37) divided into separate coxites, each bearing a long paramere about 3.5–3.9 times longer than wide (when measured as a slide preparation) each side with a seta laterad to the base. Paramere with glandular region in apical third of dorsal surface. Penis with longitudinal opening with glandular regions on each side.

Lateral cerci about twice the length of urotergite X, consisting of eight articles with the last five articles divided into subarticles with setae as well as some very long trichobothria (Figure 38). Median filament broken in the holotype but the remaining six basal articles without sensory cones, with setae and short trichobothria as well as some very strong, apically forked macrochaetae ventrally. Cerci of mature males with sensory cones on the inner ventral surface of the first two or perhaps three articles. This arrangement can vary from individual to individual but also from side to side on the same specimen (Figures 39–42). Generally with two subequal cones on the basal segment (occasionally just one), followed by a larger and one smaller cone on the second article and in one case with a third cone on the second article (Figure 42). One specimen also had a slightly modified spine on the third article (Figure 40). Remaining articles without cones (cones only visible on right lateral cercus in drawing of terminal filaments of holotype as they are obscured under the edge of the left cercus due to its orientation).

Female

As for male except pedicel of antennae lacking fovea, urosternite VIII (Figure 43) and IX (Figure 44) divided into separate coxites. Underside of urotergite X lacking the fields of cones and cerci without basal cones. Subgenital plate (Figure 44) shorter than wide at its base and ovipositor not very thick, of about 11 articles, just surpassing apex of stylets IX. Apical articles of ovipositor (Figures 45 and 46) with anterior gonapophyses having acute triangular apex and about six slightly stronger setae with slightly rounded tips as well as fine tapering setae and usual subapical field of hooks.

ETYMOLOGY

The species is named *crypta* from the Latin word for underground passage, referring to it living within small cavities deep underground.

Dodecastyla rima sp. nov.

Figures 47–82

http://www.zoobank.org/urn:lsid:zoobank.org:act:ABE1C706-457E-4065-858F-151455076140

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** (HW 0.63), Cape Preston, c. 69 km NNW. of Pannawonica, drill hole NB1 (21°02'05.70"S, 116°09'25.50"E), 26 September 2007, scraping 18 m, J.S. Cocking, M.D. Scanlon (WAM E84087) on two slides.

Paratypes

Australia: ***Western Australia*:** 1 (HW 0.60), same data as holotype (WAM E84088) in alcohol; 1 (HW 0.55), same drill hole as holotype, 23 April to 18 June 2008, trap, J.S. Cocking, C. Rumens-Thomber (WAM E84089) in alcohol (somewhat desiccated); 1 (HW 0.68), same data as previous (WAM E84090) in alcohol (somewhat desiccated); 1 (HW 0.60), same data as previous (WAM E84091) in alcohol (somewhat desiccated); 1 juv. (HW 0.50), same data as previous (WAM E84092) in alcohol (somewhat desiccated); 1 juv. (HW 0.48), as previous (WAM E84093) in alcohol (somewhat desiccated); 1 (HW 0.65), same data as previous (WAM E84094) in alcohol (somewhat desiccated and in two pieces); 1 (HW 0.68), Cape Preston, c. 66 km NNW. of Pannawonica, A34 (21°04'16.70"S, 116°08'28.30"E), 11 February 2008, scraping 25 m, J.S. Cocking, M.D. Scanlon (WAM E84082) on two slides (somewhat desiccated); 1 juv. (HW 0.43), same data as previous (WAM E84083) in alcohol (quite dirty); 1 juv. (HW 0.60), same drill hole as previous, 1 August 2007, stygofauna net 33 m, J.M. McRae, M.D. Scanlon (WAM E84079) in alcohol; 1 juv. (HW 0.45), same data as previous (WAM E84080) in alcohol; 1 (HW 0.70), same drill hole as previous, 12 February 2008, scraping 25 m, J.S. Cocking, M.D. Scanlon (WAM E84081) on two slides; 1 (HW 0.65), Cape Preston, c. 65 km NNW. of Pannawonica, A1 (21°04'38.10"S, 116°08'35.40"E), 11 February 2008, scraping, J.S. Cocking, M.D. Scanlon (WAM E84076) in alcohol; 1 (HW 0.58), Cape Preston, c. 64 km NNW. of Pannawonica, PH25 (21°05'11.50"S, 116°08'25.80"E), 12 February 2008, scraping 24 m, J.S. Cocking, M.D. Scanlon (WAM E84095) on two slides; 1 (HW 0.60), Cape Preston, c. 65 km NNW. of Pannawonica, A8 (22°04'30.70"S, 116°08'36.30"E), 27 September 2007, scraping 25 m, J.S. Cocking, M.D. Scanlon (WAM E84084) on two slides; 1 (HW 0.60), same data as previous (WAM E84085) in alcohol (quite dirty); 1 (HW 0.58), same data as previous (WAM E84086) in alcohol (quite dirty and curled over); 1 (HW 0.73), Cape Preston, c. 64 km NNW. of Pannawonica, Z8, (22°05'27.60"S, 116°08'14.20"E), 11 March 2009, scraping 30 m, J.S. Cocking, H.J. Barron (WAM E84133) in alcohol (quite dirty posteriorly and distended); 1 (HW 0.70), same drill hole as previous, 12 February 2008, scraping 24 m, J.S. Cocking, M.D. Scanlon (WAM E84096) in alcohol (affected by fungus?); 1 (HW 0.73), same data as previous (WAM E84132) in alcohol (affected by fungus?); 1 (HW 0.55), Cape Preston, c. 65 km NNW. of Pannawonica, A25 (21°04'25.50"S, 116°08'40.20"E), 11 February 2008, scraping 30 m, J.S. Cocking, M.D. Scanlon (WAM E84077) in alcohol; 1 juv. (HW 0.45), same data as previous (WAM E84078) in alcohol.

DIAGNOSIS

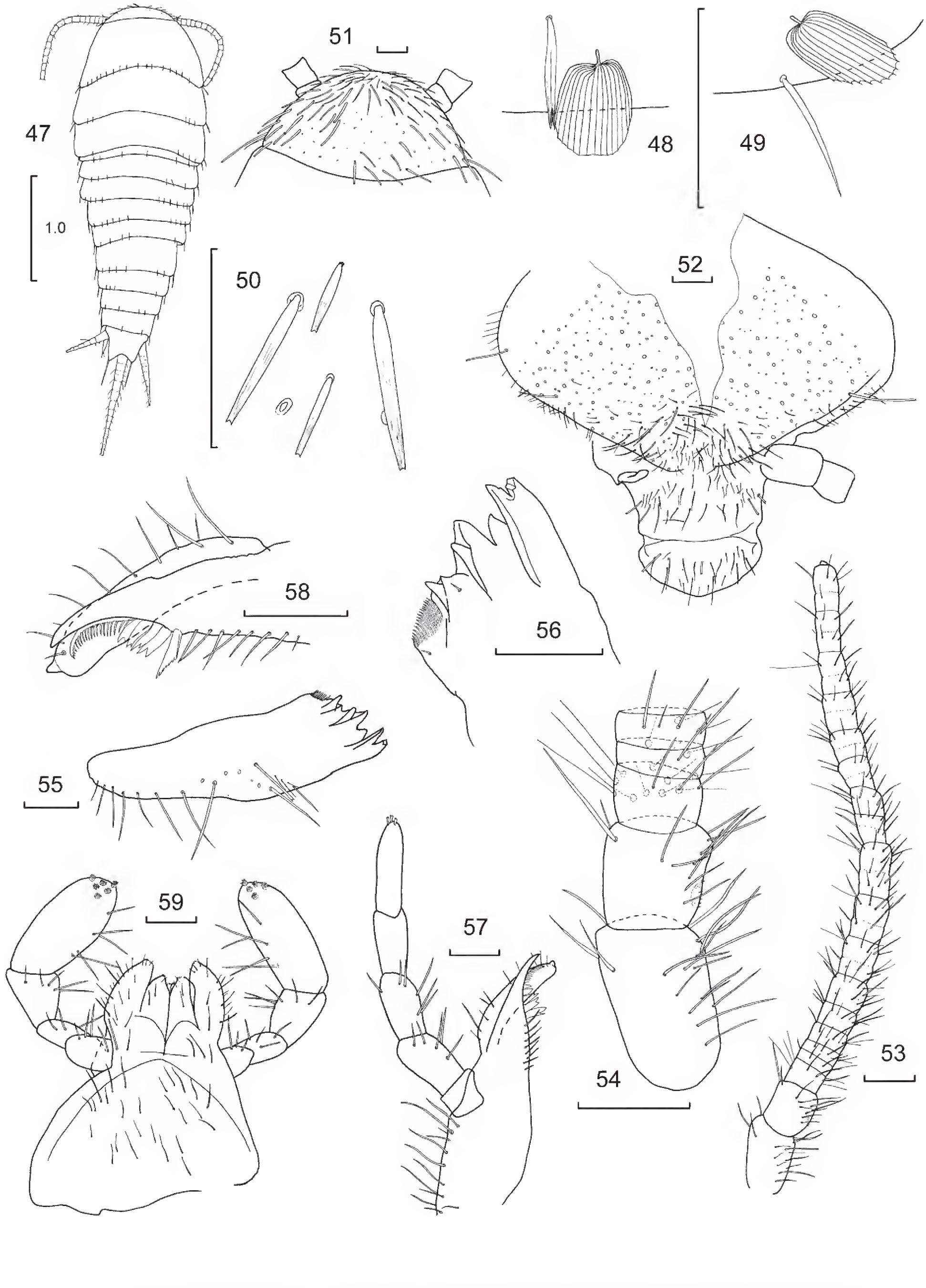
This species is also distinguished from *Dodecastyla bifida* by its much longer antennae (> 19 articles vs 13–14) and by the simple lateral macrochaetae of its urotergites (vs abiesiform macrochaetae in *D. bifida*). It can be distinguished from *D. crypta* sp. nov. by the presence of a mound of spinulae (glandular?) mediad to the cones on the underside of urotergite X, by the larger number of abiesiform macrochaetae on the nota (18–22 vs 11–18), the shorter scape relative to the pedicel, the longer cerci, the shorter maxillary palp, the more robust prothoracic legs and the smaller number of setae on the posterior margin of urosternite VIII of the male.

DESCRIPTION

Male

Body length: up to about 4.2 mm in (WAM E84095), up to 4.8 mm in (WAM E84096) but many specimens showing distended abdomens; thorax length up to 1.65 mm (or about 0.31–0.44 H+B); thorax width: 1.20 mm, widest at meso or metathorax; antennae incomplete in most specimens, up to 3.4 mm or about 0.7 times H+B, cerci up to 0.7 mm (about 0.2 H+B) extending beyond the apex of urotergite X by more than the length of urotergite X, median dorsal appendage up to 1.6 mm (0.21 H+B). Body ateluroid (Figure 47). Scales in alcohol preserved specimens without colour, ovoid, rays on dorsal scales (Figure 48) not or only just protruding beyond the margin of the scale, those on the scales of the ventral surface protruding slightly (Figure 49). Macrochaetae mostly simple or delicately apically bifurcate. All tergites with a submarginal row of abiesiform macrochaetae. Posterior setae of head modified to flattened, longitudinally striated and bluntly forked apically (Figure 50).

Head as in Figures 51 and 52, wider than long, without scales but with numerous setae, some simple others apically bifurcate, those nearer to the posterior margin flattened almost abiesiform scale-like setae. Antennae (Figure 53) long with at least 19 articles (in WAM E84081), pedicel about two thirds as long as scape, with fovea consisting of a small circular field of several short pointed setulae on the inner ventral face, article three with 10 trichobothria (Figure 54). Flagellum incomplete in all dissected specimens, article four short, articles five to eight becoming longer, articles subdivided from article eight or nine, articles four to fifteen with two trichobothria, remaining articles with only one trichobothria. When articles are subdivided the trichobothria are only present on the distal subarticle. Mandibles strong with row of macrochaetae along the outer face (Figure 55), and well developed incisor and



FIGURES 47–59 *Dodecastyla rima* sp. nov., holotype male (WAM E84087) unless otherwise indicated by specimen number: 47, habitus, composite drawing of holotype with terminal filaments of WAM E84081, note that the thorax is somewhat unnaturally curled giving the false impression that the head is largely hidden by the prothorax (compare with Figure 51); 48, dorsal scale; 49, ventral abdominal scale; 50, setae on head (WAM E84084); 51, head, in normal position (in alcohol) (WAM E84088); 52, head; 53, antenna, incomplete; 54, idem, enlargement of five basal articles; 55, mandible; 56, idem, enlargement of incisor and molar regions; 57, maxilla (smaller setae omitted from palp); 58, idem, enlargement of apices of lacinia and galea; 59, labium (smaller setae omitted from palp). All scale bars = 0.1 mm.

molar regions (Figure 56). Maxilla (Figures 57 and 58), lacinia with single strong tooth, five lamellate processes that merge into a pectinate process that is about the same length as the tooth, eight setae on inner margin proximal to lamellate processes. Galea equal to or slightly longer than the lacinia with single prominent apical papilla. Maxillary palp fairly short, only about twice the length of the lacinia (from the base of the palp). Apical article of maxillary palp 1.3–2.5 times longer than wide and 1.5–2.1 times longer than penultimate article, with three apical papillae. Second and third articles with some stronger setae subapically. Labium (Figure 59) longer than wide; labial palp not elongated, apical article ovoid (Figure 60 - although the last article is not oriented flat in the illustrations and appears narrower than it actually is), about 1.3–1.6 times longer than wide with some long quite strong setae and the usual 3+2+1 apical papillae.

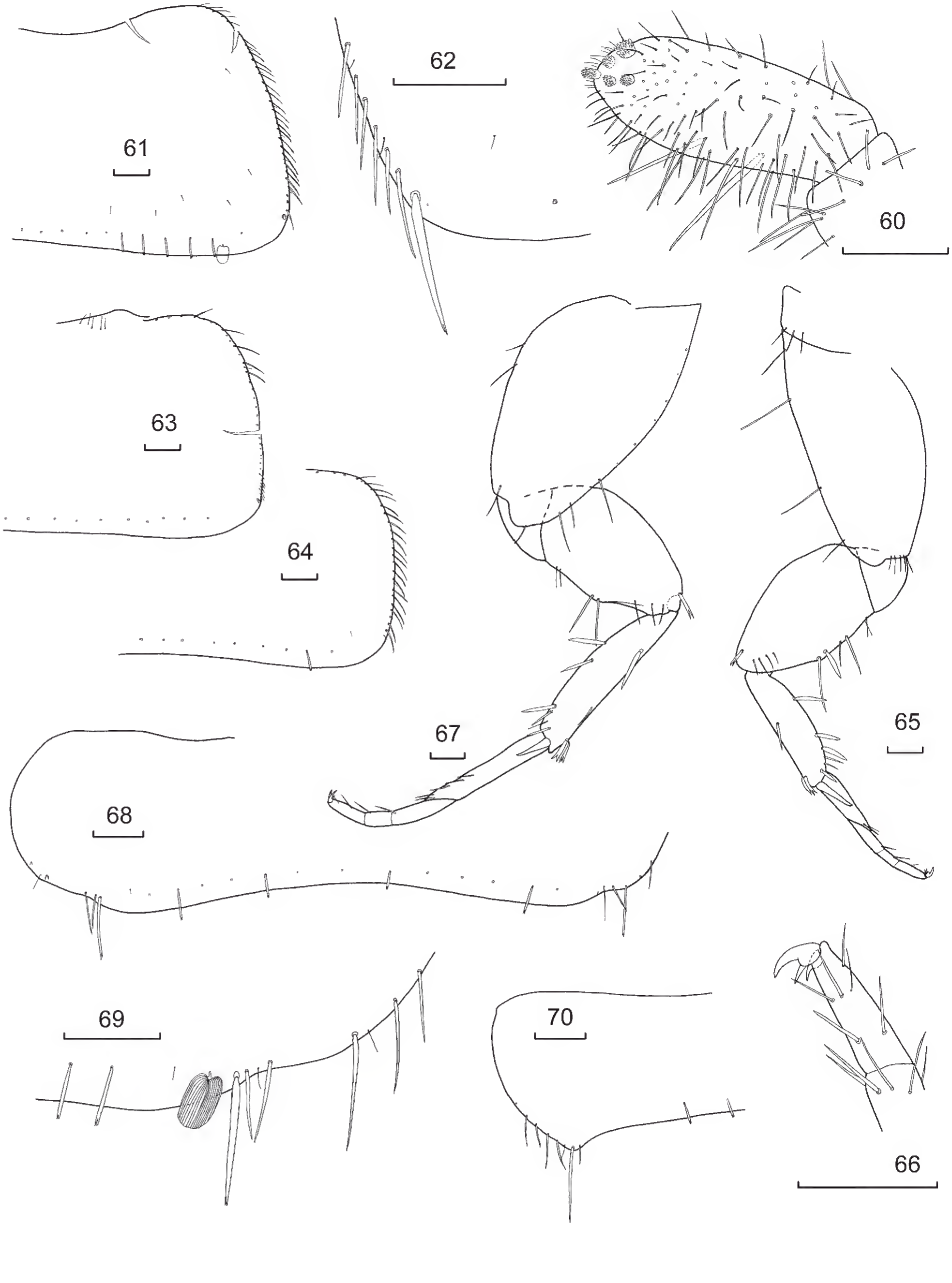
Thoracic nota (Figures 61–64) with posterior border straight on pronotum, becoming slightly concave on the meso and meta nota. Lateral margins with small simple setae and a larger macrochaeta in the posterior corner on each side as well as a few small setulae at intervals; the larger macrochaeta in the postero-lateral corners can be quite variable in size, from large as in Figure 62, to not much different to the adjacent setae. Posterior border with row of subequidistant abiesiform setae set back from margin with ends just surpassing the posterior margin of the nota; several small setulae on disc in lateral quarter of each nota and some placed anterior to and between the marginal setae. About 19–22 abiesiform macrochaetae on pronotum, about 18–20 on the mesonotum and 18–21 on metanotum. Abiesiform seta of the nota only about as long as the adjacent scales.

Legs quite long (Figures 65–67), tibia L/W ratio of legs PI 2.7–3.9, PII 3.3–4.0, PIII 4.0–5.0; tarsi L/W ratio PI 5.9–7.8, PII 7.0–9.6, PIII 10.2–12.4. Some scales on coxae of PII and PIII. Transverse row of about two apically bifurcated and two simple macrochaetae across the small sclerite at the base of the coxa of PI. Coxa with some thin and several longer stronger setae along the outer margin and several stronger setae on the end of the inner margin over the articulation. Trochanter short with fine setae. Femur with a long and a strong macrochaeta on the posterior bulge and another longer macrochaeta between these and the trochanter and a single longer lyriform spine subdistally on the outer margin. Tibia with four strong macrochaetae on posterior margin as well as three strong lyriform spines subapically, a strong macrochaeta on the outer margin and a long ventral apical spur. Tarsi with four articles, basal article almost as long as the following three articles together, with oblique join to next article. Pretarsus with three claws, the medial claw being slightly shorter, straighter and thinner; lamellate pulvilli absent.

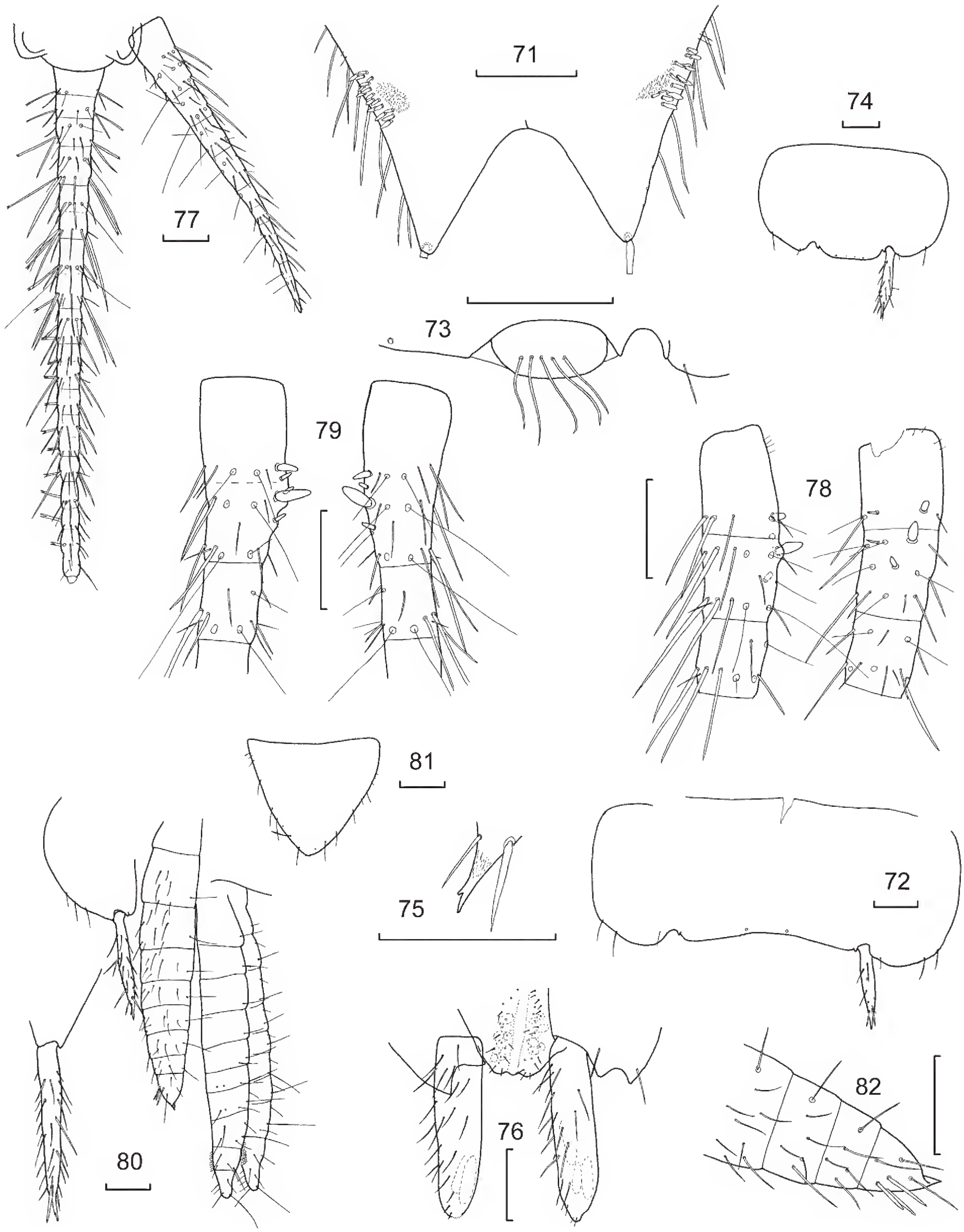
Urotergites become progressively narrower posteriorly. Paratergites fold strongly under body with distinct carina at the side of the body; suture between tergite and paratergite often indistinct but easily torn during dissection. Much of urotergite I hidden under the metanotum. Posterior margin of urotergites I–IX (Figures 68–70) with submarginal row of sub-evenly spaced abiesiform setae that are only slightly longer than the adjacent scales (most laterad abiesiform seta may be slightly longer than the others). Abiesiform setae decrease in number posteriorly from around 16 on urotergite I to nine on urotergites V and VI, six on urotergite VIII and only four on urotergite IX. Lateral corners with chaetotaxy similar to *D. crypta* (i.e. one longer delicately apically bifurcate and then two shorter simple setae at the level of the suture with the paratergites, as well as two or three simple or delicately apically bifurcate setae on the outer margin (Figure 69). There may be occasional setulae at about the level of the row of abiesiform setae, notably at each end of row as well as associated with the lateral chaetotaxy. Urotergite IX (Figure 70) with postero-lateral corner only slightly produced backwards with one strong macrochaeta and one small adjacent seta mediad to the macrochaeta and three or four setae along each lateral margin. Urotergite X similar in shape for both sexes, posterior corners acute but not strongly elongated, each bearing an apical macrochaeta. Underside of urotergite X of male on each side, with a raised bump provided with numerous tiny spinulae (glandular?) mediad to small fields of sensory cones, adjacent to similar cones on the cerci (Figure 71).

Urosternite I (lost in slide of holotype) with 1+1 small submedial setae and a single small seta on the posterior corner. Urosternites II–VII (Figure 72) with 1+1 submedial apically bifurcate submarginal setae and two to three small setae on the postero-lateral corners, without small setulae on posterior margin mediad to the stylets. Urosternite VI also with 1+1 eversible vesicles (Figure 73) each armed with four to five simple setae in a single row. Urosternite VII with pseudovesicles. Urosternite VIII of male (Figure 74) produced between the stylets with two stronger and two weaker submarginal setae. Six pairs of stylets present (on urosternites IV–IX), those on IX about twice as long as those on the anterior segments. Stylets with distinct apical spine sometimes (but not always) with small subapical ‘thorn’ (Figure 75), as well as some stronger setae subapically and along their length, in addition to smaller setae. Urosternite IX in male (Figure 76) divided into separate coxites, each bearing a long paramere about 3.7-4.2 times longer than wide (when measured as a slide preparation) with a seta on the coxite laterad to its base. Paramere with glandular region in apical third of dorsal surface and several simple setae. Penis with longitudinal opening with glandular regions on each side.

Lateral cerci more than twice the length of urotergite X, consisting of eight or nine articles with the last four articles divided into subarticles with setae as well as some very long trichobothria (Figure 77); the division between the two basal articles often very difficult to see. The median filament (broken in holotype) of eleven or twelve articles subdividing from about the fourth and further subdivided from about the sixth, with setae and long trichobothria as well as some very strong, apically forked macrochaetae ventrally. Cerci of mature males with sensory cones on the inner and or ventral surface of first two articles. The arrangement can be somewhat variable (compare Figures 78 and 79). Basal article with



FIGURES 60–70 *Dodecastyla rima* sp. nov., holotype male (WAM E84087) unless otherwise indicated by specimen number: 60, last article of labial palp; 61, pronotum, right side; 62, idem, detail of left postero-lateral corner; 63, mesonotum, right side; 64, metanotum, right side; 65; prothoracic leg, smaller setae not shown (WAM E84095); 66, idem, pretarsus and last article of tarsus (WAM E84095); 67 metathoracic leg, smaller setae not shown (WAM E84095); 68, urotergite III (?); 69, urotergite VIII, detail of left posterior corner; 70, urotergite IX, left side (WAM E84081). All scale bars = 0.1 mm.



FIGURES 71–82 *Dodecastyla rima* sp. nov., holotype male (WAM E84087) unless otherwise indicated by specimen number: 71, urotergite X; 72, urosternite IV or V; 73, detail of left eversible vesicle VI (WAM E84081); 74, urosternite VIII of male; 75, apex of stylet IX (WAM E84081); 76, parameres and penis as well as part of coxites IX; 77, cerci and median dorsal appendage of female (WAM E84081); 78, basal three articles of cerci of male; 79, ibid, of another male (WAM E84095); 80, genital region of female with urosternites VIII and IX and their stylets (WAM E84081); 81, subgenital plate (WAM E84081); 82, detail of apex of anterior gonapophysis (WAM E84081). All scale bars = 0.1 mm.

one medium and sometimes a smaller cone, which may be located more ventrally rather than in line with the other cones. Second article with one larger cone as well as one or two smaller cones, the division between these two articles often difficult to see, remaining articles without cones.

Female

As for male except pedicel of antennae lacking fovea, urosternite VIII and IX (Figure 80) divided into separate coxites, underside of urotergite X lacking the fields of cones and field of setulae, cerci without basal cones, subgenital plate (Figure 81) shorter than wide at its base. Ovipositor (Figures 80) not very thick, of about 10 articles, apex of anterior gonapophyses (Figure 82) with acute triangular apex and three slightly stronger setae with more rounded tips as well as fine tapering setae; posterior gonapophyses with rounded tips and usual subapical field of hooks.

ETYMOLOGY

The species is named *rima* from the Latin word for crack or crevice, referring, as for the previous species, to it living within small cavities deep underground.

Troglotheus **gen. nov.**

http://www.zoobank.org/urn:lsid:zoobank.org:act:60D167B5-9AF1-4AB5-8FDF-F8E48A4B76EB

TYPE SPECIES

Troglotheus bifurcus sp. nov.

DIAGNOSIS

The genus differs from others in the tribe Atopatelurini by the number of stylets (six pairs), the absence of dorsal setae or macrochaetae on the nota (only some small setulae) and the head with only simple or apically bifid setae.

DESCRIPTION

Medium sized, elongate ateluroid shape, thorax not strongly wider than abdomen, devoid of pigment. Scales multi-radiate with ribs on dorsal scales only slightly surpassing the margins, while those on the ventral surface protrude a little further beyond the posterior margin. Head with mostly simple or apically bifid setae. Antennae with more distal articles subdivided, pedicel of male with obscure fovea.

Mouthparts typical for the Atopatelurini. Mandibles with well developed molar and incisor regions. Maxilla with single-toothed lacinia, a pectinate prostheca that is about the same length as the lacinia, galea about the same length as the lacinia and equipped with a single prominent apical papilla. Maxillary palp with usual three apical feathered papillae. Labium typical for the Atopatelurini.

Lateral margins of thoracic nota with small setae and a single larger macrochaeta in each postero-lateral corner; posterior margin of all nota without setae or macrochaetae, only with some small setulae. Legs typical for Atopatelurini, with a single subapical lyriform spine on each femur and three on each tibia; pretarsi with two lateral claws and a medial empodial claw; pulvilli absent.

Abdomen with paratergites folding strongly around and slightly under the body with distinct carina at the outermost point on the more anterior segments. Posterior margins of urotergites I–IX glabrous, with only a single macrochaeta and some smaller setae present on each of the postero-lateral corners. Urotergite IX with small postero-lateral lobes. Urotergite X very long and deeply incised on the posterior margin, with a single macrochaeta at the apex on each side; underside of urotergite X in males with field of cones on each side near the base of the cerci.

Urosternite I glabrous, urosternites II–VII (VIII in) with 1+1 submedial setae. Stylets present on segments IV–IX. Eversible vesicles on VI, each armed with several simple setae, pseudovesicles on VII. Posterior margin of urosternite VIII in male protruding between the stylets. Urosternite IX of male divided into separate coxites, each bearing a long paramere. Penis with longitudinal opening.

Cerci of male with cones on the medial ventral surface of the basal two articles; median filament without cones or modified chaetotaxy.

Female lacking fovea on antennae, also lacking cones on underside of urotergite IX and base of cerci. Subgenital plate subtriangular. Ovipositor short and thick.

ETYMOLOGY

The name of the genus derived from the Greek word *troglo* for cave to highlight the subterranean habitat of the type species, combined with the suffix *-theus*, commonly used with Atelurinae.

DISCUSSION

The genus clearly fits within the Atopatelurini but is unusual in lacking dorsal setae or macrochaetae. It has all the other key characters such as the exposed head covered with setae (without scales), the typical unmodified body scales, the male pedicel with a fovea but lacking an apophysis, a non-elongated prostheca and a single conule on the galea, lyriform spines on the legs, urosternite VI with exsertile vesicles bearing a row of setae, pseudovesicles on urosternite VII, the typical female genitalia with subgenital plate and large spindle-shaped ovipositor bearing only fine setae and the base of the cerci and the underside of urotergite X in mature males with cones and the median dorsal appendage without modified chaetotaxy.

Apart from the absence of dorsal chaetotaxy and the very elongate urotergite X, it is close to other genera in the tribe, especially *Dodecastyla* with which it also shares the same number of stylets. *Dodecastyla* in turn is quite close to *Pseudogastrotheus* and another, as yet undescribed genus, which have stylets on urosternites VI–IX and V–IX respectively. The number of stylet pairs within the Zygentoma is however not necessarily a strong character to determine higher groups as it seems to be fairly unstable. While it is practical at the moment to sort the species into genera based on the number of pairs of stylets, this may eventually be shown to be of secondary significance.

Troglotheus bifurcus **sp. nov.**

Figures 83–119

http://www.zoobank.org/urn:lsid:zoobank.org:act:623678E0-12DA-4E7E-BF04-6B6961C64CD6

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** (HW 0.70), Valley of the Queens, c. 60 km N. of Tom Price, drill hole SM1573 (22°07′13.5"S, 117°44′54.6″E), 13 March 2013, scraping from hole 8 m deep, J.S. Cocking and S.R. Bennett (WAM E84068) on two slides.

Paratypes

Australia: ***Western Australia*:** 1 (HW 0.68), same data as holotype (WAM E84069) in two pieces- head thorax and abdominal segments I-VII in alcohol and abdominal segments IX & X (missing ovipositor) on one slide; 1? (HW 0.65), same data as holotype (WAM E84070) in alcohol (incomplete specimen, head, thorax and abdominal segments I–VII); 1 (HW ?), Valley of the Queens, c. 60 km N. of Tom Price, SM5423 (22°06′42.6"S, 117°45′39.8″E), 13 March 2013, scraping 25 m, J.S. Cocking and S.R. Bennett (WAM E84071) in alcohol (posterior half only); 1 (HW 0.83), Valley of the Queens, c. 60 km N. of Tom Price, SM1934 (22°07′11.9"S, 117°44′54.6″E), 13 September 2012, scraping 11 m, J.S. Cocking and S.R. Bennett (WAM E84072) in two pieces, each part mounted on separate microscope slide (i.e. head, thorax and abdominal segments I–IV on one slide, V–IX on another); 1? (HW 0.83), same data as previous (WAM E84073) incomplete specimen, head, thorax and abdominal segments I-III on one slide; 1 (HW 0.83), Valley of the Queens, c. 60 km N. of Tom Price, SM1934 (22°07′13.0"S, 117°45′36.4″E), 3 September 2011, scraping 10 m, J.S. Cocking and S.R. Bennett (WAM E84074) on two slides (incomplete, head, thorax and abdominal segments I, VII-X); 1 (HW 0.80), same data as previous (WAM E84075) in two pieces with each piece mounted on a separate slide (i.e. head, thorax and abdominal segment I on one slide, abdominal segments V(VI)-X on the other).

DESCRIPTION

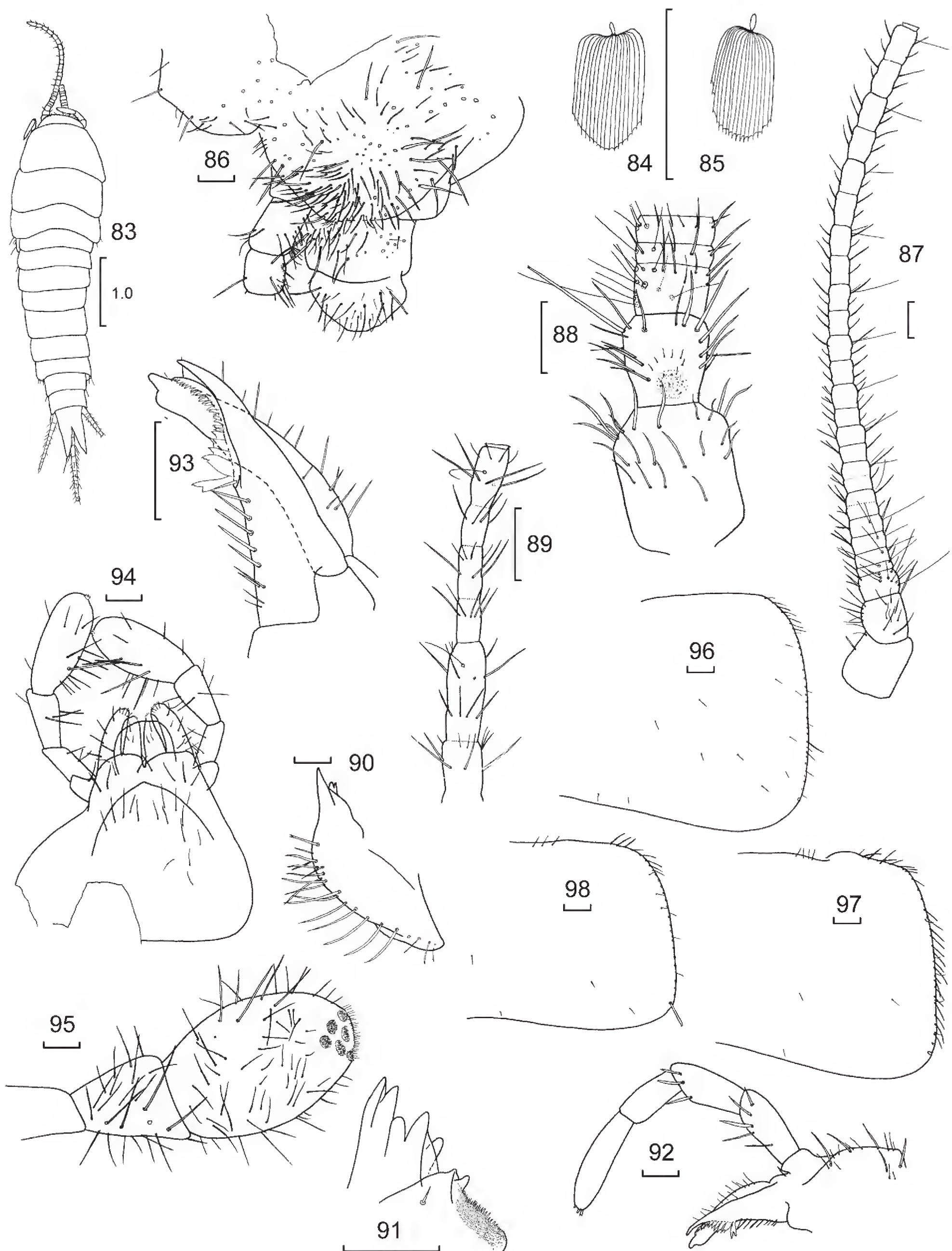
Male

Body length: up to about 7.4 mm (WAM E84072); thorax length: 2.1 mm (or about 0.25 times H+B); thorax width: 1.35 mm, widest at meso or metathorax; cerci damaged in all specimens except for one partial specimen (WAM E84069) where the cerci extend a little beyond the apex of urotergite X. Median dorsal appendage broken in all specimens but almost complete in specimen (WAM E84069) being about twice the length of the cerci and extending well beyond the posterior limit of urotergite X. Body form elongate tapering (Figure 83), quite narrow at posterior of abdomen (0.63 mm), devoid of pigment. Scales in alcohol preserved specimens without colour and ovoid, their rays only just surpassing their free border, slightly more so with the ventral scales (Figures 84–85). Macrochaetae mostly simple or some apically bifurcate, those near the posterior corners of the head thicker than the rest, although most of the posterior macrochaetae are lost in the specimens available.

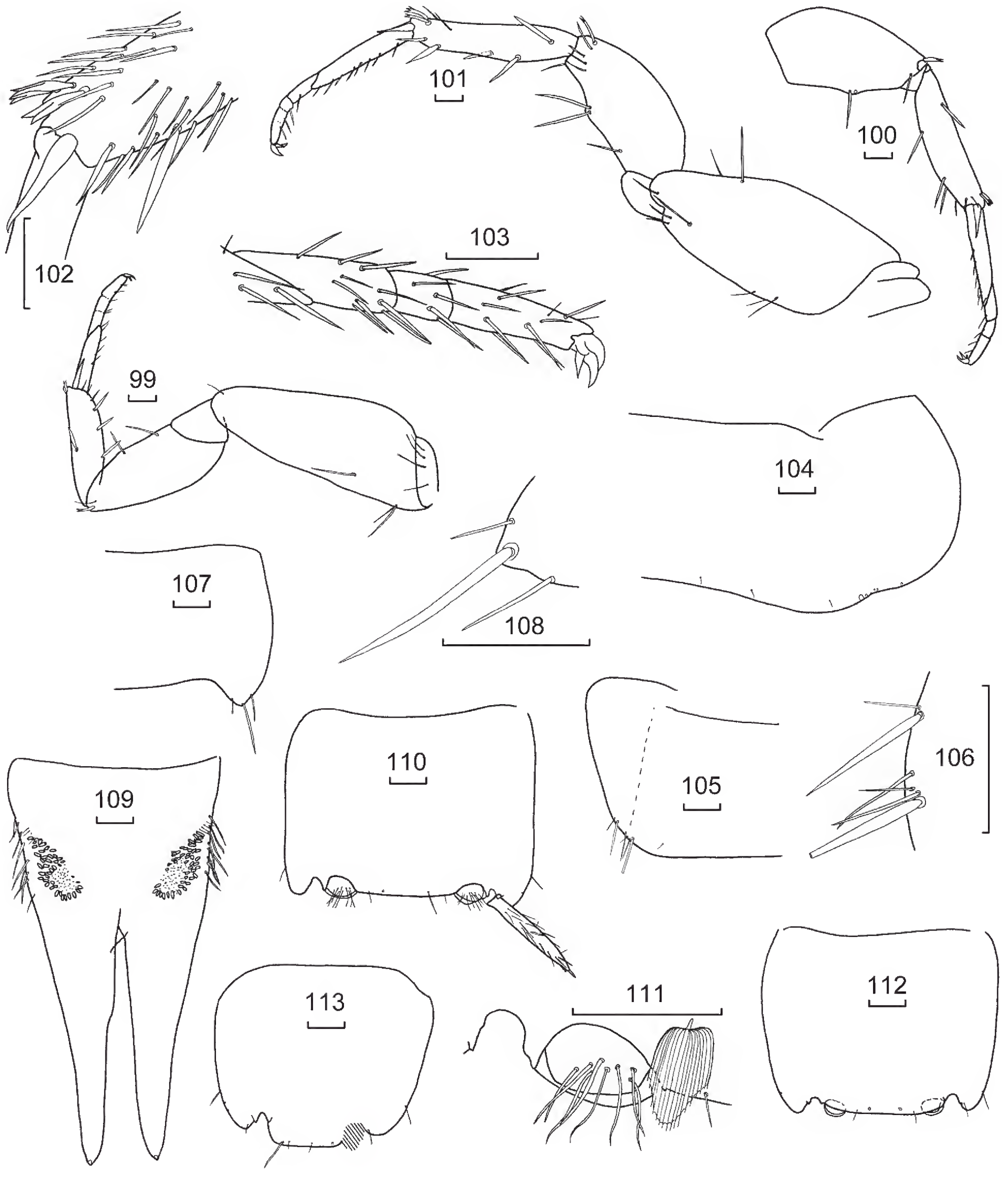
Head (Figure 86) not much wider than long, without scales and with numerous curved macrochaetae some quite robust. Antennae (Figure 87) incomplete in all specimens, (only the basal 17 articles preserved in holotype; 20+ articles in WAM E84074). Pedicel (Figure 88) about half as long as the scape, with obscure fovea consisting of a small circular field of short pointed setulae on the inner ventral face, article three with eight (?) trichobothria, although an indistinct joint with article four can sometimes give the impression that there are ten trichobothria; article four short, articles five to seven becoming longer, articles subdivided from article eight or nine, article 20 obscurely further subdivided into a total of four subarticles (Figure 89), articles four to fourteen (or sixteen in WAM E84074) with two trichobothria, remaining articles with only one trichobothria, when articles subdivided the trichobothria are present only on the distal subarticle. Mandibles strong with row of macrochaetae along the outer face (Figure 90), and well developed incisor and molar regions (Figure 91). Maxilla (Figure 92), lacinia with single strong tooth, several lamellate processes that merge into a pectinate process that is about the length of the tooth or slightly shorter, five single and two pairs of small setae on inner margin proximal to lamellate processes. Palp of medium length about two and a half times the length of the lacinia (from the base of the palp), apical article of maxillary palp 4.3–5.3 times longer than wide and 1.5–2.4 times longer than penultimate article. Ultimate article with three apical papillae; second and third articles with some stronger setae subapically. Labium (Figure 94) longer than wide; labial palp somewhat elongated, apical article long ovoid shape (Figure 95), about 1.5–1.6 times longer than wide with usual 3+2+1 subapical papillae.

Thoracic nota (Figures 96–98) with posterior border slightly concave. Lateral margins with small simple setae and a single macrochaeta in the posterior corner on each side, posterior border glabrous, several small setulae on disc and along margins.

Legs very long (Figures 99–103), tibia L/W ratio of legs PI 3.8–4.1, PII 4.3–5.6, PIII 4.1–5.2; tarsi L/W ratio PI 6.8–8.7, PII 8.3–11.5, PIII 13.8–14.6. Legs with numerous short and long setae and some scales on the coxae only of PII and PIII. Transverse line of about three apically bifurcated and one simple macrochaetae across the small sclerite at the base of the coxa of PI. Coxae with some longer thin setae along the outer margin and one on face and several stronger setae on the end of the inner margin over the articulation. Trochanter short. Femur with two long macrochaetae on the posterior bulge and a single longer lyriform spine subdistally on the outer margin. Tibia with three strong macrochaetae on ventral face and posterior margin as in Figures 99–101, as well as three strong lyriform spines subapically on the outer margin and a long ventral apical spur (Figure 102). Tarsi with four articles, basal article elongate (on PII and PIII longer than



FIGURES 83–98 *Troglotheus bifurcus* sp. nov., holotype male (WAM E84068) unless otherwise indicated by specimen number: 83, habitus, composite of holotype and terminalia of WAM E84069; 84, dorsal scale; 85, ventral scale; 86, head (damaged posteriorly during dissection); 87, antenna, incomplete; 88, idem, enlargement of five basal articles; 89, idem, enlargement of most apical surviving articles (WAM E84074); 90, mandible; 91, idem, enlargement of incisor and molar regions; 92, maxilla (smaller setae omitted from palp); 93, idem, enlargement of apices of lacinia and galea; 94, labium (smaller setae omitted from palp); 95, idem, enlargement of apical article of palp; 96, pronotum, right half; 97, mesonotum, right half; 98, metanotum, right half. All scale bars = 0.1 mm, unless otherwise indicated.



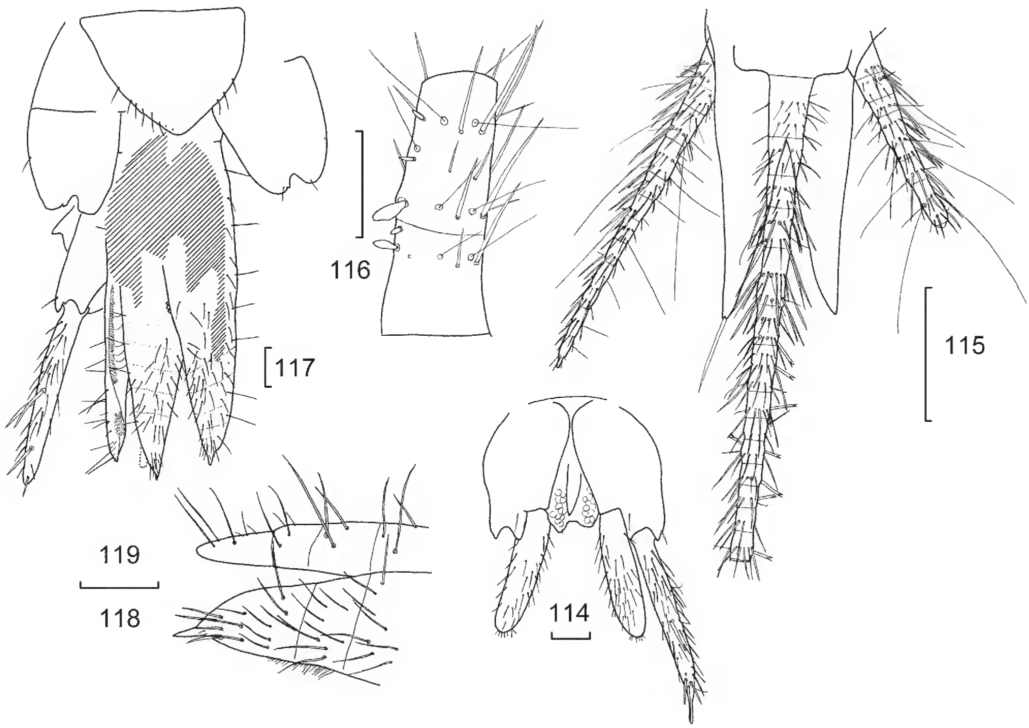
FIGURES 99–113 *Troglotheus bifurcus* sp. nov., holotype male (WAM E84068) unless otherwise indicated by specimen number: 99, prothoracic leg (smaller setae omitted); 100, mesothoracic leg excluding coxa and trochanter (smaller setae omitted); 101, metathoracic leg (excluding smaller setae); 102, idem, distal end of tibia; 103, idem, distal three articles of tarsus and pretarsus; 104, urotergite III, right half; 105, urotergite VIII, left half; 106, idem, enlargement of postero-lateral chaetotaxy; 107, urotergite IX, right half; 108, idem, enlargement of postero-lateral chaetotaxy; 109, urotergite X, from below (WAM E84074); 110, urosternite VI; 111, idem, enlargement of right vesicle; 112, urosternite VII; 113, urosternite VIII. All scale bars = 0.1 mm.

following three articles together) with oblique join to next article. Pretarsus with medial claw being slightly shorter and straighter than the laterals (Figure 103).

Urotergites become progressively much narrower posteriorly; paratergites fold strongly under body with distinct carina at the side of the body. Suture between tergite and paratergite often indistinct but tergite easily tears along this line when preparing slide preparations. Urotergites I–VIII without setae or macrochaetae along posterior margin except for one macrochaeta, two smaller setae and a setula on the margin either side of the suture with the paratergite and another marginal seta and setula a small distance laterad of these (Figures 104–106). There are also four setulae somewhat remote from the posterior margins. Urotergite IX (Figure 107) with postero-lateral corner produced backwards with one macrochaeta and a smaller seta on each side (Figure 108). Urotergite X (Figure 109) with greatly elongated posterior corners in both sexes and each apex with an apical macrochaeta. Underside of urotergite X in the male with fields of sensory cones surrounding an open area of granular appearance located on each side adjacent to similar but larger cones on the cerci.

Urosternite I glabrous (middle region of sternite damaged in holotype but intact on WAM E84074). Urosternite VI with 1+1 eversible vesicles (Figures 110 and 111) each armed with eight or nine simple setae in two irregular rows; urosternite VII (Figure 112) with pseudovesicles. Urosternite VIII (Figure 113) of male produced medially with setulae mediad to the submarginal 1+1 setae. Stylets on IX almost twice as large as those on the segments IV–VIII. Stylets with distinct apical spine and some stronger and also smaller setae. Urosternite IX in male (Figure 114) divided into separate coxites, each bearing a long paramere. Paramera with glands on dorsal surface, about 4-5.8 times longer than wide (when measured as a slide preparation) with a seta laterad to the base and another near the posterior end of the lateral margin. Penis with longitudinal opening with glandular regions on each side.

Terminal filaments mostly incomplete; one female specimen, consisting only of urotergite X and urosternite



FIGURES 114–119 *Troglotheus bifurcus* sp. nov., holotype male (WAM E84068) unless otherwise indicated by specimen number: 114, urosternite IX of male with stylet IX and parameres; 115, terminal filaments and outline of urotergite X (WAM E84069); 116, base of cercus (WAM E84074); 117, urosternites VIII and IX of female, with ovipositor and stylet IX (cross-hatched area indicates dark material within specimen obscuring view) (WAM E84075); 118, apex of gonapophyses VIII; 119, apex of gonapophyses IX (WAM E84075). All scale bars 0.1 mm.

IX (without ovipositor) had one complete lateral cercus and most of the median cercus (Figure 115). The lateral cerci consists of about ten articles with setae as well as some very long trichobothria, the cercus extending to about the level of the apex of the macrochaeta on the end of urotergite X. The median filament consists of more segments (> 15), with setae and short trichobothria as well as some very strong, apically forked macrochaetae ventrally. Cerci of mature males with two sensory cones on the inner ventral surface of the first article, followed by a larger and two smaller cones on the second article (Figure 116), remaining articles apparently without cones (somewhat obscured by dust and urotergite X in holotype).

Female

As for male except, pedicel of antennae lacking fovea, urosternite VIII and IX (Figure 117) divided into separate coxites, underside of urotergite X lacking the fields of cones, cerci without basal cones, subgenital plate (Figure 117) slightly shorter than wide at its base and ovipositor short and thick, of about 10 articles, not quite attaining the end of stylets IX, apical articles as shown in figures 118 and 119.

ETYMOLOGY

The species is named *bifurcus* from the Latin word for two-pronged, referring to the greatly elongated and bifurcated urotergite X.

DISCUSSION

Schäffer's original description of *Lepismina bifida*, while very good for the time, contained some errors such as the number of abdominal stylets and it did not adequately describe the dorsal chaetotaxy. Silvestri (1898) moved the species and other Atelurinae, to his new genus *Grassiella*. In 1902 Silvestri redescribed the species based on topotypic material, correcting the number of abdominal stylets to six pairs, suggesting the head was almost bare, describing the dorsal chaetotaxy as a submarginal row of narrow truncate apically bifurcate scales and reporting the pretarsus to consist of two outer curved claws and another acute apically curved claw between them. Escherich (1903) believed Silvestri's *Grassiella bifida* could not be the same as *Lepismina bifida* Schäffer because it had a different number of stylets. He renamed Silvestri's 1902 description and material as *Grassiella silvestrii*. In 1905, after receiving material from both Schäffer and Silvestri, Escherich confirmed the material to be the same thus making *G. silvestrii* a junior synonym of *G. bifida*. At the same time, he transferred all described atelurin species to *Atelura* v. Heyden, 1855. In 1905, Silvestri redescribed the species as *Atelura bifida*; this time describing the head as having numerous and quite long setae, especially at the front, but does not mention if they are simple or of flattened appearance. In 1912, Silvestri restored the genus *Grassiella* with a revised description but made no specific mention of *bifida*. Wygodzinsky (1958) suggested the species may not belong in *Grassiella* due to the presence of rows of macrochaetae on the posterior borders of the tergites and the absence of a process on the pedicel of the male. Paclt (1974) examined new material from Chile as well as two syntypes and erected the genus *Dodecastyla* for the species including mention, for the first time, of skin-like empodial appendages (pulvilli?) at the base of the claws. Unfortunately there is some concern that the more recent material from Coronel examined by Paclt may not be the same species as that described by Schäffer and Silvestri because the male specimen, still in acohol, is much larger (almost 5 mm vs 3.5 mm). Further specimens from Coronel in the Hamburg collection referred to by Paclt (1979) are not atelurins at all but belong to the Microcoryphia. Some of Schäffer's original material is still available in the University of Hamburg entomological collection but is described as being quite dirty and/or in rather poor condition and quite fragile (Koch pers. comm.). Given the existing ambiguities, a redescription of this species would be welcome and could be completed more satisfactorily when additional topotypic material is obtained.

BIOLOGY, HABITAT AND DISTRIBUTION

The presence of Atelurinae in deep subterranean habitats is somewhat surprising, however the observations of atelurin silverfish in caves mentioned in the Introduction suggests that some species, like the rest of the Nicoletiidae, are not averse to travelling or living far underground. In addition it would appear that their potential hosts may also take advantage of deep subterranean habitats, perhaps only in the search for water in otherwise arid regions.

Troglotheus bifurcus is known from only four drill holes within 1.9 km of each other at the Valley of the Queens. Three are on the valley floor and the fourth is on the lower slopes of surrounding hills. Between one and six other species of troglofauna were collected together with *Troglotheus bifurcus*. These were hemipterans, cockroaches, symphylans, pauropods, pseudocorpions, beetles, schizomids and nicoletiin silverfish (*Trinemura* sp. and *Hemitrinemura* sp.). Unidentified ants were collected with *Troglotheus bifurcus* at three of the holes, while termites were collected with *Troglotheus bifurcus* at two holes and were recorded in a sample from a third hole when *Troglotheus bifurcus* was not collected (but probably present in the matrix around the hole). Thus, it is possible *Troglotheus bifurcus* is associated with an ant or termite species.

The likely range of *Dodecastyla crypta* is unclear at this stage. Animals with similar morphology to that of *Dodecastyla crypta* are frequently collected during troglofauna sampling from west of the Packsaddle Range along the Hamersley Range to Ophthalmia Range and east of Newman. We have insufficient morphological and genetic information to determine whether these animals represent a single taxon and have selected animals from a single drill hole in

the Packsaddle Range as the type series. It is likely, however, that *Dodecastyla crypta* occurs at least throughout the Packsaddle and Jirrpalpur Ranges and we treat all animals in this area as *Dodecastyla crypta*, giving the species an east-west range of at least 20 km.

Holes yielding *Dodecastyla crypta* were on ridge lines or hills. Four and five other troglofauna species, respectively, were collected with *Dodecastyla crypta* at drill hole PSD0149R on 11 April and 27 June 2010. These were unidentified hemipterans, cockroaches, schizomids and centipedes. Unlike *Troglotheus bifurcus*, the occurrence of *Dodecastyla crypta* does not appear to be obviously associated with ants or termites. Ants were present in only about a quarter of the holes in the Jirrpalpur and Packsaddle Ranges that yielded what is considered to be *Dodecastyla crypta*. Termites were present in a single hole.

Most records of *Dodecastyla crypta* in the Packsaddle and Jirrpalpur Ranges were collected by scraping but five trap samples from depths of 15, 35, 50, 51 and 51 m yielded specimens. These specimens were much deeper than any ants or termites are likely to occur and provides further evidence that it is unlikely that ants or termites are hosts for *Dodecastyla crypta*. We suggest that *Dodecastyla crypta* either lives independently or is associated with another troglofauna species.

In the case of *Dodecastyla rima*, all material examined was included in the type series. It was collected over a smaller range than *Dodecastyla crypta* (6 km vs 20 km) although a very small creek lies between two of the collection sites (e.g. the holotype was collected from the north eastern side of the small creek and the female paratype from the south-west). While variability was seen in the configuration of cones on the cerci and underside of urotergite X in the males, all male specimens displayed the raised areas with small points mediad to the combs and all displayed the higher number of abiesiform setae on the tergites compared to those seen in *Dodecastyla crypta*.

Dodecastyla rima was collected on 18 occasions, with up to four other troglofauna species collected in the same sample. Altogether, six other groups of troglofauna were collected with *Dodecastyla rima* (pseudoscorpions, schizomids, diplurans, centipedes, beetles and enchytraeid worms). A species of nicoletiin silverfish belonging to the genus *Hemitrinemura* was collected four times. *Dodecastyla rima* was collected with unidentified ants on four occasions and once with termites.

Despite the occasional co-occurrence with termites or ants, none of the three atelurin silverfish described here displays strong apomorphies that we would associate with an obligate dependency on a social insect host (usually seen more with termitophiles than myrmecophiles) so any relationships with ants or termites may be more facultative than obligatory. The co-occurrence with troglobitic species, such as schizomids, and the fact at least 15 other (undescribed) species of Atelurinae have been collected from deep in exploration holes (J.M McRae unpublished data) suggests that atelurin silverfish are regular inhabitants of subterranean habitats in the Pilbara.

MORPHOLOGY

All three subterranean species have quite thin and delicate cuticles and their general body form is less robust than seen in other epigean Atopatelurini species such as *Australiatelura tasmanica* (Silvestri, 1949). The frequent collection of the species in exploration holes, suggests however, a degree of troglomorphism, although by no means extreme. *Troglotheus bifurcus* shows the greatest degree of troglomorphism with the body being longer and more slender than other atelurins. None of the three species however shows the greatly elongated appendages of highly adapted troglobites. Nor do they have exceptionally long setae. While this may be related to their occurrence in small spaces across the subterranean landscape, rather than occurrence in the large voids of caves, we believe it best to consider the species as troglophiles rather than obligate subterranean insects because of the lack of strong troglomorphies. They might quite easily be able to survive within the nests of ants or termites, where habitat conditions are also quite stable. However life as an inquiline species can be hazardous and the silverfish would need to retain the ability to move rapidly to escape capture by the hosts. The development of long spindly legs and slower movements typical of troglobites are unlikely to be advantageous under such conditions. It is possible that the adaptations we usually consider as beneficial to an inquiline existence such as the shortening of appendages, the tendency to ovoid shape and the need for speed, are in conflict with those we consider as beneficial for a troglobitic existence.

ZOOGEOGRAPHY

Assuming *D. crypta* and *D. rima* have been correctly placed within *Dodecastyla*, the presence of this genus in both Chile and Australia suggests an Antarctic/Gondwana origin for the genus, possibly in line with that known for the *Nothofagus* forests of both countries. In their analysis of the paleogeography of the region, Cook and Crisp (2005) note that Australia and South America separated from Antarctica between 30 and 50 My ago. If this represents the last common ancestor then the close similarity between the Australian and Chilean species would suggest a quite conservative morphology within this genus. The Australian ancestors of these two *Dodecastyla* species were probably forest dwelling species that took refuge, perhaps in company with their hosts, deeper within the soil as the climate dried out from the mid-Miocene (c. 10–15 My ago).

Troglotheus on the other hand is much more derived that other Australian Atopatelurini. It is the only species to lack setae on the posterior margins of the tergites. The extremely elongated urotergite X is also unique,

although in its basic shape with a deep triangular incision and the presence of cones on the underside in the males, it conforms to the usual pattern. In the arrangement of urosternal vesicles it is like many of the other genera including *Dodecastyla*, *Atopatelura* Silvestri, 1908 from Central Africa, *Arabiatelura* Mendes, 1995 from the Middle East, *Australiatelura* Mendes, 1995 and *Ausallatelura* Smith, 2007 both from Australia, the widespread *Pseudogastrotheus* Mendes 2003 from Africa, South and SE Asia, Australia and Brazil, and *Rasthegotus* Mendes, 2001 from Africa. *Ecnomatelura* Wygodzinsky, 1961 from South Africa differs in vesicles VI being located laterad to the stylets. Only *Dodecastyla* has the same number of stylets. *Allatelura hilli* Silvestri, 1947 and *Galenatelura deflexa* Smith, 2009, both endemic to Australia, do not have the characteristic vesicles with setae on urosternite VI and their placement within the Atopatelurini is probably yet to be fully established.

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A new diminutive species of *Varanus* from the Dampier Peninsula, western Kimberley region, Western Australia

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ABSTRACT – *Varanus* lizards in Australia are moderately diverse and include a radiation of small-bodied species that occur in arid or tropical environments. *Varanus brevicauda* is the smallest species, with an elongate body and short prehensile tail and is associated with spinifex clumps in arid environments. Recently collected unusual specimens at the north-western edge of the range of *V. brevicauda* on the Dampier Peninsula, Western Australia, had an even more elongate body and also co-occurred with typical *V. brevicauda*. This led us to conduct a morphological and molecular genetic systematic appraisal of the two morphotypes. We found that the more elongate specimens were highly divergent genetically from both typical *V. brevicauda* and another related species, *V. eremius*, with the three lineages forming a polytomy. Morphologically, the elongate specimens are most similar to *V. brevicauda*, but possess a more elongate body, less robust head and limbs, distinctive scales on the front of the arms that are large, squarish and lacking surrounding granules and a plainer pattern and colouration. The co-occurrence of both forms on the Dampier Peninsula in combination with the extent and pattern of genetic divergence and presence of key morphologically diagnostic traits unequivocally demonstrates that more elongate form is a new species, which we describe here. The new species may be of conservation concern owing to the small range of the only known specimens and development proposals in the area.

KEYWORDS: Goanna, monitor lizard, *Varanus brevicauda*, *Varanus sparnus* sp. nov.

INTRODUCTION

Lizards of the genus *Varanus* Merrem, 1820, commonly referred to as goannas or monitors, are a moderately diverse group with over 70 species from Australia, south-east Asia, India, the Middle East and Africa. Australia is the most species-rich region with 31 species, including a radiation of small to very small-bodied species within the subgenus *Odatria* Gray, 1838 (Pianka et al. 2004). *Varanus* show strong conservatism in body shape, with most species having long, pointed heads and tails (King and Green 1999). Body proportions, however, can differ substantially among species, with relative head and tail lengths differing widely in association with differences in ecology (Thompson and Withers 1997; Openshaw and Keogh 2014).

Within the small-bodied Australian *Odatria* group there are three widely-distributed arid zone species: *V. brevicauda* Boulenger, 1898, *V. acanthurus* Boulenger, 1885 and *V. eremius* Lucas & Frost, 1895. *Varanus brevicauda* is the smallest species of *Varanus*, with a snout-vent length of around 120 mm and a total length of about 250 mm owing to its short tail (hence the specific name) (Storr et al. 1983; Pianka 2004). It occurs along the west coast and extends eastwards and inland through the sandy deserts as far as the Simpson Desert in western Queensland (Wilson and Swan 2010). This species is an active burrower, with relatively straight claws on the hands, capable of digging their own tunnels and foraging for food among *Triodia* clumps and along sand dunes (Pianka 2004).

Recently, several unusual specimens assignable to *V. brevicauda* have been collected from the extreme north-west of the species' range, from near Coulomb Point on the Dampier Peninsula, north of Broome in the western Kimberley region (Figure 1). This area is characterised by sandy soils and pindan vegetation communities (McKenzie 1983). The specimens have a more elongate and gracile appearance than typical *V. brevicauda* and a more subdued pattern. We carried out

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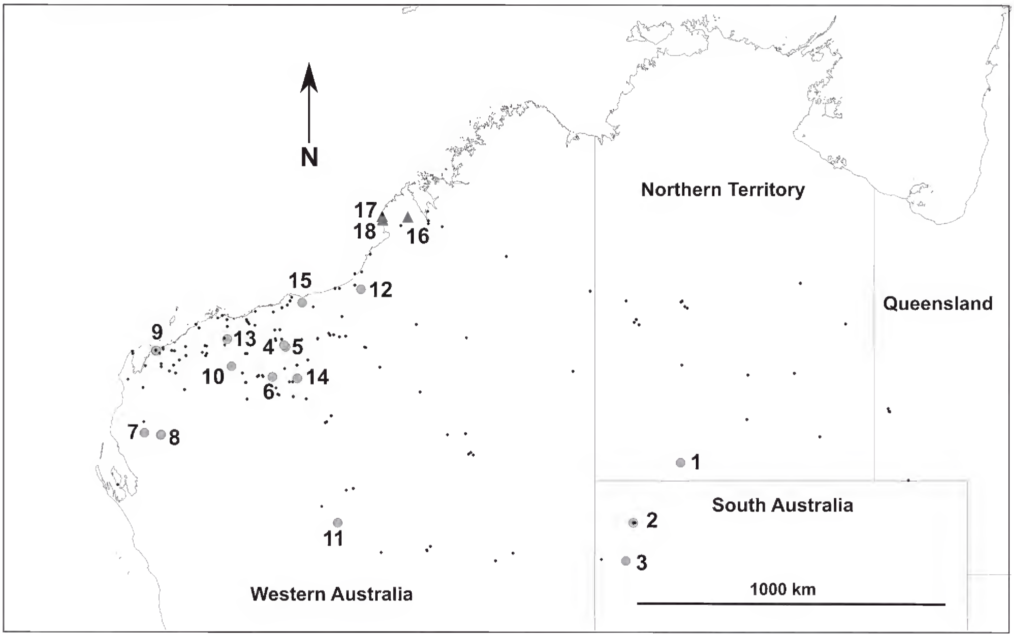

FIGURE 1 Map showing the distribution of *Varanus brevicauda* (dots) and *V. sparnus* sp. nov. (triangles) based on Atlas of Living Australia voucher records (small dots) and locations from which molecular genetic data were obtained (large symbols).

a molecular genetic analysis to assess the distinctiveness of these specimens from 'typical' *V. brevicauda* sampled throughout its range. This genetic evidence indicated that the elongate specimens are equally distant genetically to *V. brevicauda* and *V. eremius*. Examination of specimens also revealed a suite of morphological characters to distinguish the new form. Here we describe this population as a new species of *Varanus*.

METHODS

MORPHOLOGY

Specimens were examined from the collections of the Western Australian Museum (WAM; where new type material is deposited). We examined three preserved specimens of the elongate form, plus one live captive specimen, and compared these with 20 *V. brevicauda* from throughout the rest of its range in Western Australia, including from the Dampier Peninsula (Appendix 1). We compared the two forms qualitatively and measured and counted other characters. Table 1 presents the morphological variables assessed and how they were measured. Measurements were made with electronic callipers to the nearest 0.1 mm, with SVL, TailL and TrunkL to 0.5 mm (broken tails were excluded). Individuals were sexed on the basis of everted hemipenes in males or of conspicuous gravidity in females, or by direct examination of the gonads.

MOLECULAR GENETICS

Frozen or alcohol preserved tissues were available from 31 *Varanus* vouchers (Appendix 1). DNA was extracted from using a Puregene DNA isolation kit (Gentra Systems, Minneapolis, U.S.A.) following the manufacturer's protocol for DNA purification from solid tissue. An ~886 bp fragment of the mitochondrial genome, including the 3′ end of the *NADH dehydrogenase* subunit *4* (*ND4*) gene (710 bp) and the tRNA genes *tRNAHis*, *tRNASer* and the 5′ end of *tRNALeu* (176 bp), hereafter referred to as *ND4*, was amplified and sequenced using the forward primers *ND4*: 5′-TGACTACCAAAAGCTCATGTAGAAGC-3′ or *ND4*: 5′-ACCTATGACTACCAAAAGCTCATGTAGAAGC-3′ with the reverse primer Leu1: 5′-CATTACTTTTTACTTGGATTTGCACCA-3′. Each PCR was carried out in a volume of 25 ml with a final concentration of 1X GeneAmp PCR Gold buffer, 2–4 mM MgCl2, 200 M of each dNTP, 0.2 mM of each primer and 0.5 U of AmpliTaq Gold DNA polymerase (Applied Biosystems, Foster City, CA, U.S.A.). Amplifications consisted of an initial denaturation step of 94°C for 9 min, followed by 34 cycles of PCR with the following temperature profile: denaturation at 94°C for 45 s, annealing at 55°C for 45 s, and extension at 72°C for

TABLE 1 Morphological characters measured.

Character	Description
SVL	Snout-vent length
LegL	Leg length, measured from the knee patella to the tip of the 4th toe including claw
HeadL	Head length, measured obliquely from tip of snout to anterior margin of tympanum
HeadW	Head width, measured at the widest point
HeadD	Head depth, measured level with centre of the tympanum, at the highest point
SupLab	Number of supralabial scales
InfLab	Number of infralabial scales, ending with the last small scale in contact with the posterior margin of the last upper labial
MBSR	Number of midbody scale rows, counted midway between axilla and groin
4TLam	Number of enlarged subdigital lamellae under fourth toe, counted from toe junction to base of claw
PCP	Number of pre-cloacal pores
TailL	Tail length, measured from the base of the cloaca to the tip of the tail
CloSpu	Number of cloacal spurs present
ILL	Inter-limb length, measured between the forelimb and hindlimb
UArmL	Upper arm length, measured from the lower side of the axilla to the outside of the elbow
LArmL	Lower arm length, measured from the outside of the elbow to the inside of the wrist
HandL	Hand length, measured from the inside of the wrist to the tip of the 4th toe, excluding the nail
ULegL	Upper leg length, measured from the lower side of the groin to the outside of the knee
LLegL	Lower leg length, measured from the outside of the knee to the inside of the ankle
FootL	Foot length, measured from the inside of the ankle to the 4th toe, excluding the nail

1 min, with an additional final extension at 72°C for 6 min. The double-stranded amplification products were visualised on 1.5% agarose gels and purified using an UltraClean PCR clean-up DNA purification kit (Mo Bio Laboratories Inc., CA, U.S.A.) before cycle-sequencing using the BigDye Terminator v3.1 cycle-sequencing kit (Applied Biosystems). The cycling protocol consisted of 25 cycles of denaturation at 96°C for 30 s, annealing at 50°C for 15 s, and extension at 60°C for 4 min. All samples were sequenced on an Applied Biosystems 3700 DNA sequencer. These sequences were aligned with previously published *Varanus ND4* sequences, including species from clades related to *V. brevicauda* as identified by Fitch et al. (2006) and Vidal et al. (2012) (Appendix 1) with MAFFT v6.814b (Katoh et al. 2005) implemented in Geneious Pro v5.5.2.

Bayes factors were used to assess all possible alternative partitioning strategies for four data subsets: 1st, 2nd and 3rd codon positions and the tRNA in PartitionFinder v1.0.0 (Lanfear et al. 2012). The Akaike Information Criterion (AIC) and Bayes Information Criterion (BIC) were used to assess the best fit partition strategy and nucleotide substitution model for each data subset in the selected partition strategy. Sequences were analysed phylogenetically using Bayesian and maximum likelihood methods. Bayesian analysis was conducted using MrBayes v3.1.2 (Ronquist and Huelsenbeck 2003). The analysis was run with model parameters unlinked using default priors for two million generations with two independent runs and two chains sampling every 1000 generations. The first 25% of sampled trees were discarded as burn-in and convergence was assessed by examining effective sample sizes (ESS values), split frequencies of clades across runs and likelihood plots through time in TRACER v1.4.1 (Rambaut and Drummond 2007).

Net average sequence divergence between lineages (dA) was calculated in MEGA v5 (Tamura et al. 2011) as: $dA = dXY - (dX + dY)/2$, where, dXY is the average distance between groups X and Y, and dX and dY are the within-group means. Net average sequence divergence between taxa was calculated from our data and the data of Fitch et al. (2006), Smith et al. (2007), Smissen et al. (2013), Maryan et al. (2014) and GenBank accessions for *V. komodoensis* Ouwens, 1912 for sister species pairs of *Varanus* where more than one sequence was available for each member of the pair.

RESULTS

MOLECULAR GENETICS

The partioning scheme and models of nucleotide substitution for the *ND4* alignment of 460 bp chosen in Partition Finder were first codon position with HKY+G, second codon position with HKY+G and third codon position with TIM+G. Figure 2 shows a Neighbor-Joining phylogram showing relationship among mitochondrial *ND4* sequences from *V. brevicauda* and near relatives. This topology was also recovered with the Bayesian analysis. Specimens resembling *V. brevicauda* fell into two highly divergent groups: the first is widespread across the arid zone, while the second appears to be geographically restricted to the Dampier Peninsula at the north-western edge of the range of *V. brevicauda sensu lato* (Figures 1, 2). The relationships of these two groups with *V. eremius* are unresolved by our data but net average sequence divergence (*dA*) between the three exceeds that between many other sister species pairs of varanids (Table 2).

MORPHOLOGY

Table 3 presents a summary of the morphological differences between *V. brevicauda* from across its range and the elongate individuals from the Dampier Peninsula (Figure 3). The two taxa had similar dorsal patterning, although *V. brevicauda* tended to have more pronounced ocelli than the elongate specimens, giving it a bolder pattern (Figure 4). Morphologically, the elongate specimens had a more gracile appearance (Figure 4), with longer inter-limb lengths (Table 3). We also found that head depth was shallower in the elongate individuals as well (Figure 5).

FIGURE 2 Neighbour-Joining (NJ) phylogram of relationships among mitochondrial *ND4* sequences of *Varanus brevicauda* and near relatives. Numbers at nodes are NJ bootstrap proportions (left) and Bayesian posterior probabilities (right).

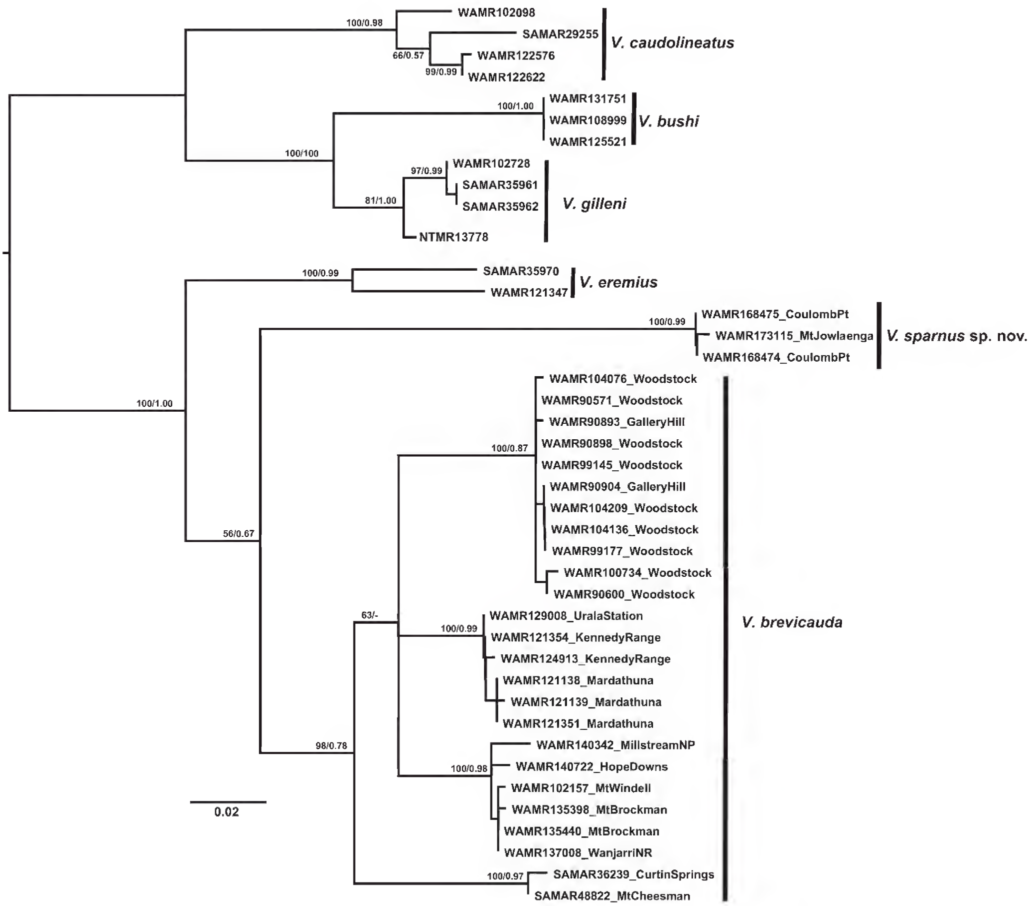

TABLE 2 Net average sequence divergence (*dA*) between sister species pairs of varanids and among *Varanus brevicauda*, *V. sparnus* sp. nov., *V. eremius* and other more distantly-related species pairs.

Sister species pair	*dA*
V. brevicauda-sparnus sp. nov.	0.134
V. eremius-sparnus sp. nov.	0.143
V. brevicauda-eremius	0.085
V. komdoensis-varius	0.125
V. mitchelli-semiremex	0.121
V. gouldii-rosenbergi	0.112
V. bushi-gilleni	0.066
V. pilbarensis-hamersleyensis	0.063
V. acanthurus insulanicus-baritji	0.019

A key difference between the two taxa observed was the appearance of the scales on the front and leading edge of the arms. The scales on the arms of *V. brevicauda senso stricto* are oval in shape and possess a ring of granules around them (Figure 6), similar to scales elsewhere on the body. In contrast, the elongate individuals had large, squarish scales on the front and leading edge of the arms, and the scales lacked small granules at their periphery (Figure 6). A further difference is that, in ventral view, the transition from the large squarish scales on the elongate individuals is quite abrupt, whereas in *V. brevicauda* the scales encircling the arm are similar in appearance with no abrupt transition (Figure 6).

TAXONOMIC CONCLUSIONS

The molecular genetic evidence strongly supported the existence of two independently evolving lineages within *V. brevicauda senso lato* (including the elongate specimens) based on reciprocal monophyly in the mitochondrial nucleotide sequence data and the extent of net average sequence divergence between the lineages relative to other recognised sister species pairs of *Varanus* (Table 2). Furthermore, nuclear gene sequence data from more than 300 loci produced from an anchored enrichment phylogenomic approach (Lemmon and Lemmon 2012) supports the highly divergent nature of the two lineages (Donnellan, Keogh, Lemmon and Lemmon, unpublished data).

The morphological evidence also supports the existence of two species, with the new species more elongate and gracile than *V. brevicauda*, and differences in scalation on the arms. Patterning and colouration differences were less apparent, although there was a trend for specimens of the elongate form to be less well-marked and to be a darker reddish-brown (at least in the two adults). Significantly, the two species are in sympatry on the Dampier Peninsula, where typical *V. brevicauda* specimens (WAM R40273, R40274, R44329) were collected 7 km to the north of the holotype of the new species. There was no evidence of individuals demonstrating intermediate morphological states, indicating a lack of gene flow between the two species.

Taken together, morphology, molecular genetics and the overlapping distributions of the two forms strongly demonstrate that the more elongate Dampier Peninsula specimens represent a new species distinct from *V. brevicauda*, which we describe below.

TAXONOMY

Family Varanidae Merrem, 1820

Genus *Varanus* Merrem, 1820

TYPE SPECIES

Lacerta varia (= *Varanus varius*) White, 1790, by subsequent designation.

Varanus sparnus sp. nov.

Dampier Peninsula Goanna

Figures 3–6

http://www.zoobank.org/urn:lsid:zoobank.org:act:039C783D-5A6C-4B79-9069-94E1C51E77C7

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia***: WAM R168486, adult male collected by R.J. Teale and G. Harold on 10 March 2009, from Coloumb Point, Dampier Peninsula (-17.4277°S, 122.1522°E).

Paratypes

Australia: ***Western Australia***: WAM R168475, adult female from Coloumb Point, Dampier Peninsula, collected on 14 March 2009 (-17.4608°S, 122.1525°E); WAM R168474, subadult, from Coloumb Point, Dampier Peninsula (-17.5736°S, 122.1694°E).

Additional material

Australia: ***Western Australia***: WAM R173115, live subadult female from 9 km south-west of Mt Jowlaenga, Dampier Peninsula (-17.4865°S, 122.9650°E).

DIAGNOSIS

A very small *Varanus* (< 120 mm SVL) with short limbs, elongate body, ridged, circular and short prehensile tail (TailL/SVL: 0.92–0.99), and relatively plain reddish-brown dorsum with widely scattered small black spots. Further distinguished from *V. brevicauda* by having a more elongate body, shorter limbs, less robust head, body and tail, and presence of enlarged squarish scales not encircled by granules on front of the arms.

TABLE 3 Summaries of characters and ratios measured for *Varanus brevicauda* and *V. sparnus* sp. nov. Means±S.D and ranges on the second line for each character are presented. See Table 1 for abbreviations. Sample sizes are listed in column headings, unless noted for individual characters below.

	V. brevicauda	*V. sparnus* sp. nov.			
Character:	N = 20 (8 , 12)	R168486 ( )	R168475 ( )	R168474 (J)	R173115 ( )
SVL	102.0±8.2 90.5–120.5	116.0	116.4	72.1	110.0
TailL	98.1±10.9 79–117	111.5	108.4	69.0	101.0
HeadL	18.2±1.2 16.0–20.5	20.1	17.9	13.6	15.9
HeadW	10.8±0.8 9.4–12.6	10.5	9.5	6.9	9.5
HeadD	8.1±0.9 6.0–9.7	7.6	7.0	5.0	7.5
SupLab	17.5±1.5 15–21	16	17	16	18
InfLab	17.1±1.1 15–19	16	16	15	18
MBSR	88.4±6.8 80–103	79	86	66	
4TLam	16.1±1.6 14–19	15	16	14	
PCP	0.4±1.4 0–6	0	0	0	0
ILL	58.2±5.7 49.2–69.1	66.6	74.1	40.2	79.7
UArmL	8.4±0.8 7.0–9.8	8.3	8.7	6.2	6.3
LArmL	6.8±0.7 4.7–7.8	6.9	7.0	4.9	7.6
HandL	9.3±0.6 8.4–10.3	10.1	8.9	6.0	8.4
ULegL	9.7±0.8 7.8–11.0	10.0	9.0	6.1	8.0
LLegL	8.7±1.0 6.6–10.2	7.6	7.8	5.6	7.3
FootL	10.5±1.2 7.4–12.3	9.9	9.6	7.2	8.6

DESCRIPTION OF HOLOTYPE (WAM R168486)

Head short (HeadL/SVL – 0.173), narrow (HeadW/SVL – 0.091) and shallow (HeadD/SVL – 0.066); snout slightly concave dorsally, narrowing to broadly rounded tip when viewed dorsally; in lateral view, snout gradually narrows to nostrils, then angles downwards to tip of snout; upper jaw protrudes slightly beyond lower jaw; eyes relatively large; nares large and directed posteriorly, posterior edge straight and defined by ridge, narrowing anteriorly; nostril opening small and positioned anteriorly and ventrally within narial opening; external ear opening large (~1.5 times width of eye), ventral portion angled forwards, anterior edge curved slightly and posterior edge straight for uppermost 1/3, then angled anteriorly; line of mouth gradually rising from snout tip to below posterior edge of eye, then straight to ventral edge of ear opening. Longitudinally oriented scales on top of head behind eyes with pronounced, straight keels; scales on top of snout protruding and irregular, lacking keels; scales above eyes with short keels; keels at back of head angled outwards.

Mental two times longer than wide, sides gradually narrowing then angling at 45° to meet at posterior terminal point; first, second and third infralabials enlarged, gradually decreasing in size from mental until the size of surrounding scales. Gular scales near edge of jaw flattened and elongate, gradually rounding towards gular fold; gular fold strong, with underlying granular scales underneath fold.

FIGURE 3 Images in life of *Varanus sparnus* sp. nov. Upper image – WAM R173115 (image by R. Ellis); lower image – holotype WAM R168486 (image by G. Harold).

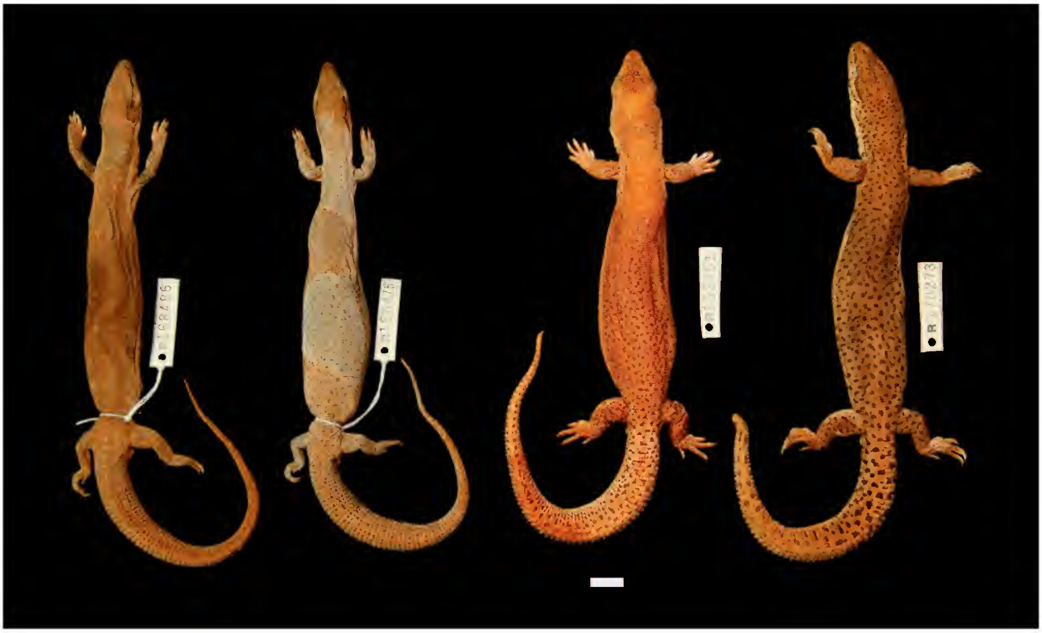

FIGURE 4 Preserved specimens of *Varanus sparnus* sp. nov. (holotype – WAM R168486; paratype – 168475), and *V. brevicauda* (WAM R163051, WAM R170273). Scale bar = 1 cm.

Torso extremely elongate (ILL/SVL – 0.57); covered in rows of small scales; dorsal scales non-overlapping and oblong with low keels bordered by 8–12 small granules (except for anterior edge); scales on sides lack keels and are rounder (less oblong); ventral scales non-overlapping, smooth (i.e. no perforation visible) and rectangular with slightly rounded posterior edge.

Limbs extremely short (UArmL/SVL – 0.072; LArmL/SVL – 0.059; ULegL/SVL – 0.086 LLegL/SVL – 0.066), with relatively large hands (HandL/SVL – 0.087) and feet (FootL/SVL – 0.085); absolute lengths: hand length > lower arm > upper arm, upper leg > foot length > lower leg. Lower arm compressed; scales on dorsal surface of lower and upper arm large, squarish and flattened, lacking surrounding granules; scales on ventral surface small; abrupt transition of scale size at leading edge of lower arm: from rows of large scales of inner lower arm to smaller scales on ventral surfaces. Scales on upper and lower surfaces of legs similar to dorsal scales on body, but smaller; scales on anterior surface enlarged and flattened, lacking surrounding granules; scales on posterior edge very small, almost granular; medial rows of scales on dorsal surfaces of hands and feet enlarged and with tightly grouped non-overlapping flat scales; palmar and plantar surfaces with small rounded scales. Fingers long with long recurved claws; toes moderately long with long recurved claws.

Cloacal spurs to either side of vent, each with 20–25 spurs arranged in 3 or 4 irregular rows; spurs flattened at base and curve upwards to fine point. Tail short and covered in regular rows of scales; dorsal scales strongly keeled and angled dorsally at posterior edge; ventral scales strongly keeled and flat; tail tip gradually tapering to a fine point; tail tip very flexible and prehensile. Measurements of the holotype and all other specimens are presented in Table 3.

Colouration

In life, ground colour of dorsum and lateral surfaces light reddish-brown; freckled with fine black spots (no ocelli present) that occupy a single scale; ventral surfaces dull yellowy-white; head with a dark blackish streak from the eye to the dorsal portion of ear opening; upper labials and scales below eye pale with light grey stippling (Figure 3). In preservative, ground colour darker reddish-brown and lower surfaces dull yellowy-white; otherwise similar to life (Figure 4).

VARIATION

The adult female (WAM R168475) is similar in most respects to the male holotype, however, this specimen has a longer torso and more gracile proportions (including slender head and neck, and thinner tail). The patterning also differs in that 1–4 scales comprise the black spots scattered on the dorsum, giving them a darker appearance. Cloacal spurs in the same position as for the male, but much shorter and without sharp tips. The juvenile (WAM R168474) is more heavily spotted in appearance than the adult female, with the black spots comprised of 4–6 scales. Otherwise, the colouration is similar in most respect to the adults. The live specimen (WAM R173115) is a subadult female, with a very subdued pattern (Figure 3).

FIGURE 5 Comparison of lateral view of heads of *Varanus sparnus* sp. nov. (top two images) and *V. brevicauda* (bottom two images). From top to bottom: WAM R168475, WAM R168486, WAM R163051, WAM R170273. Scale bar = 1 cm.

HABITAT

The three Coloumb Point specimens were collected in areas with alluvial or sandstone deposits, and broadly classed as 'pindan shrubland'. A detailed vegetation assessment for the three type specimens is provided below (M. Maier, Biota Environmental Consultants, pers. comm.). The holotype, WAM R168486, occurred with *Corymbia* sp. low trees over *Acacia monticola, A. colei, A. eriopoda* tall open scrub over mixed open grassland, on pindan soil on plain. The paratype WAM R168474 was associated with *Corymbia dampieri* and *C. polycarpa* scattered low trees over *Acacia*

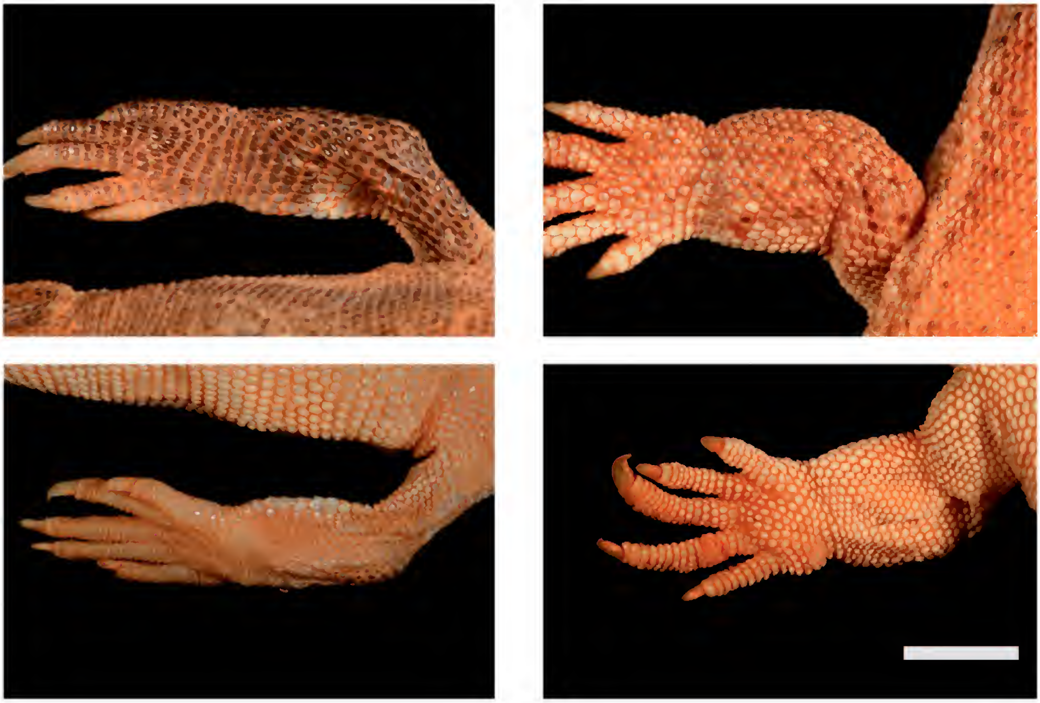

FIGURE 6 Close up comparison of the difference in arm scalation between *Varanus sparnus* sp. nov. (upper left – dorsal view; lower left – ventral view; WAM R168486) and *V. brevicauda* (upper right – dorsal view; lower right – ventral view; WAM R163051). Scale bar = 0.5 cm.

FIGURE 7 Habitat shots from the type series of *Varanus sparnus* sp. nov. from near Coloumb Point, Dampier Peninsula, Western Australia. Collection locations of paratypes WAM R168474 (left) and WAM R168475 (right).

eriopoda open shrubland; on pindan soil on plain. The paratype WAM R168475 was found amongst *Eucalyptus miniata, Terminalia ferdinandiana* low open woodland over *Acacia tumida* var. *kulparn* low closed heath over *Triodia schinzii* very open hummock grassland on exposed coastal fringe; on coastal sand in dune swale (Figure 7). The Mt Jowelaenga individual (WAM R173115) was collected in a funnel trap in pindan woodland with dense shrubs of *Acacia tumida*, scattered *Triodia caelestialis* and *Sorghum timorense* and soil consisting of red-brown sandy loam (N. Jackett, Ecologia Environment, pers. comm.).

BEHAVIOUR

Observations of the captive individual (WAM R173115) indicate that this species is a highly active burrower, excavating underneath all hard structures, such as flat pieces of wood and a heating stone (L. Umbrello, pers. comm.). This specimen readily consumed both live food (*Tenebrio* larvae, crickets) and wet cat food. Attempts to photograph this species in life were difficult, as the animals were constantly moving and rarely paused (G. Harold, R. Ellis, pers. comm.). The tail is highly prehensile, similar to that of *V. brevicauda*, possibly functioning to assist in navigating through *Triodia* clumps and shrubs.

DISTRIBUTION

The four individuals were collected from two locations approximately 90 km apart in the central portion of the Dampier Peninsula in the western Kimberley (Figure 1). This species is likely to be restricted to the peninsula (~15,000 km^2). No specimens from outside of the Dampier Peninsula (i.e. the western deserts and Pilbara region) were detected when sorting through the *V. brevicauda* specimens in the WAM collections.

ETYMOLOGY

sparnos is Greek for ‘rare’ or ‘scarce’, in reference to this species’ isolation and small range on the Dampier Peninsula. Latinised to *sparnus*, and used as an adjective.

REMARKS

Descriptions of new Australian goanna species in the past 10 years have all come from Western Australia: two from the southern Pilbara region (Aplin et al. 2006; Maryan et al. 2014), and now *V. sparnus* from the south-western Kimberley, approximately 700 km to the north. The description of *V. sparnus* further establishes Australia’s status as the most species-rich region for *Varanus* globally, with approximately 32 of 75 species (Uetz 2014).

Varanus sparnus has an apparently extremely restricted distribution, completely confined to the relatively small Dampier Peninsula area. This is in contrast to its two closest relatives, *V. brevicauda* and *V. eremius*, which nearly range across the entire arid zone that comprises the majority of the Australian continent (Pianka et al. 2004). All three species occupy sandy substrates, so other factors would explain the distributional patterns of these taxa. The sandy arid regions of the west coast of Australia has a disproportionately high number of endemics with small ranges (McKenzie et al. 2000; How and Cowan 2006; Doughty et al. 2011). Although most of these species occur further south in the mid-west and Pilbara regions, the same processes (e.g. changes in sea level that affect sand-associated taxa) may affect taxa in the Dampierland region as well. As the distribution of *V. sparnus* appears to be extremely restricted, it would be prudent for wildlife and conservation agencies to consider this species for some kind of protected status until more is known about its true range and biology.

Varanus sparnus is slightly smaller than *V. brevicauda* in maximum body size, making it the smallest known *Varanus*. In contrast, the largest member of the genus, *V. komodoensis*, reaches sizes of over 1.5 m in SVL, 3.0 m in total length and 80 kg (Jessop et al. 2006), compared to *V. sparnus* with an SVL of 116 mm, total length of 227.5 mm and mass of only 16.3 g, a remarkable size difference within a single genus of reptiles (e.g. King and Green 1999; Pianka et al. 2004; Openshaw and Keogh 2014).

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APPENDIX 1 Specimens examined for morphological[M] and molecular genetic analyses. Numbers in bold preceding localities refer localities from which genetic data were obtained (see Figure 1). *Short sequences that we did not include in Figure 2, but fall within the *V. brevicauda* clade (sequences not on GenBank but available from the authors).

Registration Number	Locality	State	Sex	GenBank	Declat	Declong
Varanus brevicauda						
SAMA R36239	**(1)** Curtin Springs	NT		KP076412	-25.392	131.767
SAMA R48822	**(2)** Mt Cheesman	SA		KP076413	-27.337	130.237
SAMA R62377*	**(3)** 166 km SSE Watarru	SA		*	-28.549	129.998
WAM R13837[M]	Derby	WA		-	-17.300	123.617
WAM R20350[M]	32 km S Derby	WA		-	-17.600	123.633
WAM R28029[M]	La Grange	WA		-	-18.683	121.767
WAM R40274[M]	Coloumb Point	WA		-	-17.367	122.150
WAM R44329[M]	Coloumb Point	WA		-	-17.367	122.150
WAM R46168[M]	Anna Plains	WA		-	-19.250	121.483
WAM R90571	**(4)** Woodstock	WA		KP076403	-21.6097	118.9878
WAM R90600[M]	**(4)** Woodstock	WA		KP076409	-21.6116	118.9556
WAM R90893[M]	**(5)** 200 m S Gallery Hill	WA		KP076410	-21.6677	119.0408
WAM R90898[M]	**(4)** Woodstock	WA		DQ525115	-21.6116	118.9556
WAM R90904[M]	**(5)** 200 m S Gallery Hill	WA		KP076411	-21.6677	119.0408
WAM R99145[M]	**(5)** 200 m S Gallery Hill	WA		KP076402	-21.6677	119.0408
WAM R99177	**(5)** 200 m S Gallery Hill	WA		KP076408	-21.6677	119.0408
WAM R100734	**(4)** Woodstock	WA		KP076407	-21.6094	118.9878
WAM R102157	**(6)** Mt Windell	WA		DQ525116	-22.6300	118.6139
WAM R104076	**(4)** Woodstock	WA		KP076404	-21.6166	118.9500
WAM R104136	**(4)** Woodstock	WA		KP076405	-21.6166	118.9500
WAM R104209	**(4)** Woodstock	WA		KP076406	-21.6166	118.9500
WAM R121138[M]	**(7)** 8 km NW Mardathuna Homestead	WA		KP076419	-24.4288	114.5000
WAM R121139[M]	**(7)** 8 km NW Mardathuna Homestead	WA		KP076417	-24.4288	114.5000
WAM R121351[M]	**(7)** 8 km NW Mardathuna Homestead	WA		KP076418	-24.4288	114.5000
WAM R121354[M]	**(8)** Kennedy Range National Park	WA		KP076416	-24.4930	115.0306
WAM R124913	**(8)** Kennedy Range	WA		KP076414	-24.5008	115.0175
WAM R129008	**(9)** Urala Station	WA		KP076420	-21.7836	114.8633
WAM R135398[M]	**(10)** Mt Brockman	WA		KP076399	-22.3000	117.3000
WAM R135440[M]	**(10)** Mt Brockman	WA		KP076398	-22.2919	117.2989
WAM R137008[M]	**(11)** Wanjarri NR	WA		KP076415	-27.3333	120.7167
WAM R139065*	**(12)** Mandora	WA		*	-19.8083	121.4639
WAM R140342[M]	**(13)** Millstream-Chichester	WA		KP076401	-21.4116	117.1561
WAM R140722	**(14)** Hope Downs	WA		KP076400	-22.6736	119.4161
WAM R140985*[M]	**(9)** Urala Station	WA		*	-21.7827	114.8697
WAM R161599*	**(15)** Goldsworthy	WA		*	-20.2419	119.5740

Registration Number	Locality	State	Sex	GenBank	Declat	Declong
Varanus sparnus sp. nov.						
WAM R168486[M]	Coulomb Point	WA			-17.4277	122.1522
WAM R168474[M]	**(18)** Coulomb Point	WA	-	KP076422	-17.5736	122.1694
WAM R168475[M]	**(17)** Coulomb Point	WA		KP076423	-17.4608	122.1525
WAM R173115[M]	**(16)** 9 km SW Mt Jowlaenga	WA		KP076421	-17.4865	122.9650
Varanus eremius						
SAMA R35970	2 km W Purni Bore	SA	-	DQ525114	-26.28	136.08
WAM R121347	30 km S Carnarvon	WA	-	DQ525113	-25.1313	113.7681
Varanus caudolineatus						
SAMA R29255	57 km S Leonara	WA	-	DQ525139	-29.37	121.27
WAM R102098	Wongida, Barlee Range	WA	-	DQ631874	-22.9666	115.8500
WAM R122622	18.5 km SE Wooramel	WA	-	DQ631876	-25.7105	114.5994
WAM R122576	18 km SE Wooramel	WA	-	DQ631875	-25.6805	114.6217
Varanus bushi						
WAM R131751	Hamersley Station	WA	-	DQ631883	-22.4452	117.8797
WAM R125521	North Pilbara	WA	-	DQ631882	-21.5000	117.5000
WAM R129912	West Angelas iron ore mine	WA	-	DQ631877	-23.1858	118.7544
Varanus gilleni						
WAM R102728	Little Sandy Desert	WA	-	DQ631872	-24.5925	120.2631
SAMA R35961	Alka Seltzer Bore	SA	-	DQ525138	-26.33	136.01
NTM R13778	no locality data	-	-	DQ525137	-	-

A new species of troglobitic *Anatemnus* (Pseudoscorpiones: Atemnidae) from the Pilbara bioregion of Australia

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ABSTRACT – A new species of the pseudoscorpion genus *Anatemnus*, *A. subvastus*, is described from subterranean environments in the Pilbara bioregion of Western Australia. Like *Oratemnus cavernicola* from New South Wales, it lacks eye spots, and has slightly elongated appendages and pallid colouration. It is known from only a small area of less than 20 km^2. We also attribute *Oratemnus cavernicola* to the genus *Anatemnus*, forming the new combination *Anatemnus cavernicola* (Beier, 1976), but note that the generic assignment of both species should be reviewed pending an assessment of all genera of Atemninae.

KEYWORDS: taxonomy, morphology, subterranean

INTRODUCTION

The semi-arid Pilbara bioregion of north-western Australia is a hotspot for subterranean biodiversity, with numerous new and distinctively modified troglobitic and stygobitic species being described over the past decade. Arthropods such as insects, arachnids and crustaceans dominate the fauna (Eberhard et al. 2005), with the arachnid fauna including schizomids (Harvey et al. 2008), spiders (Burger et al. 2010; Baehr et al. 2012) and pseudoscorpions (Harvey and Edward 2007; Harvey and Volschenk 2007; Edward and Harvey 2008; Harvey and Leng 2008a, 2008b). This fauna has generated much interest due to the interplay between the extraction of minerals, principally iron-ore, and conservation of a relictual and highly distinctive subterranean fauna.

Amongst samples collected from subterranean ecosystems in the Hamersley Range of the Pilbara bioregion were some unusual pseudoscorpions of the family Atemnidae with distinctly troglobitic facies including slender pedipalps and legs, pallid colour and no eyes. To better document the subterranean fauna of the region, we here describe this atemnid species. The atemnid fauna of continental Australia is restricted to just four species of *Oratemnus* Beier, 1932, *O. cavernicola* Beier, 1976, *O. curtus* (Beier, 1954), *O. distinctus* (Beier, 1948) and *O. punctatus* (L. Koch and Keyserling, 1885) (Beier 1948, 1954, 1966, 1976; Harvey 2013). The new species shows many similarities with *O. cavernicola*, particularly in the disposition of the trichobothria of the fixed chelal finger, which differs from the arrangement of other species of *Oratemnus*. Instead, the pattern is more reminiscent of species of *Anatemnus* Beier, 1932, and we suggest that both species can be accommodated in this genus.

MATERIAL AND METHODS

The holotype used in this study was collected from subterranean environments using baited colonisation traps, which are left suspended at depths through bore hole profiles for a minimum of six weeks. Traps were baited with locally sourced leaf litter material, which is soaked and irradiated to kill surface fauna and facilitate breakdown of the litter. Other specimens were collected by scraping a weighted net vertically up the sides of bore holes, which collects fauna utilising the side of the

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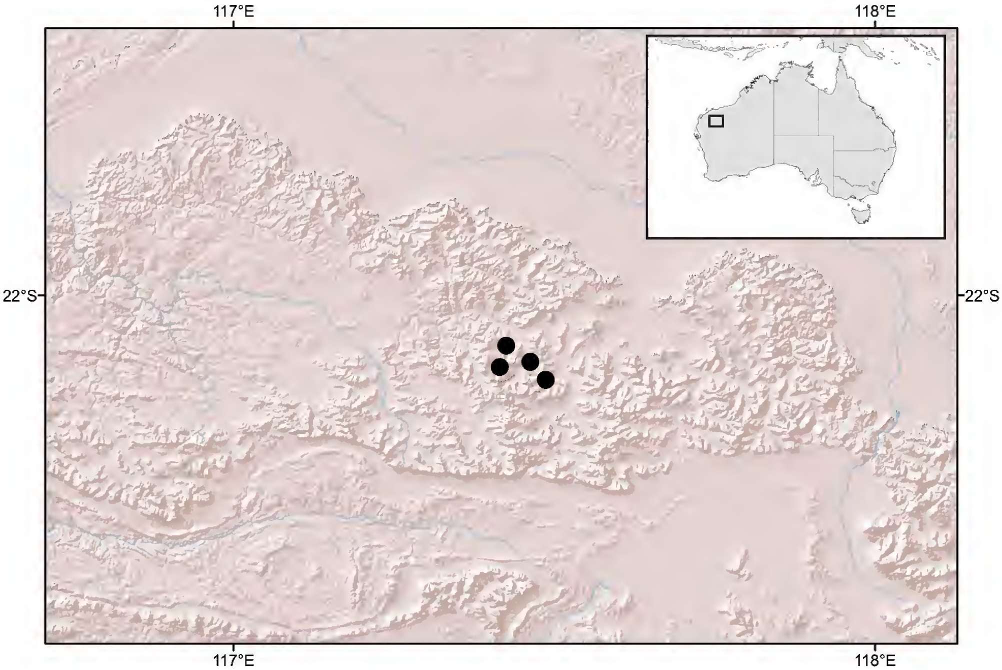

FIGURE 1 Known distribution of *Anatemnus subvastus* sp. nov.

bore (Halse and Pearson 2014). Collected specimens are lodged in the Western Australian Museum, Perth (WAM), and were examined using a temporary slide mount prepared by immersion of the specimens in 50% lactic acid at room temperature for several days. They were then mounted on a microscope slide with a 10 mm coverslip supported by small sections of 0.25 or 0.35 mm diameter nylon fishing line. After study the specimens were returned to 75% ethanol with the dissected portions placed in 12 x 3 mm glass genitalia microvials (BioQuip Products, Inc.). Specimens were examined with a Leica MZ–16A dissecting microscope, and a Leica DM2500 compound microscope, the latter fitted with interference contrast, and illustrated with the aid of a drawing tube attached to the compound microscope. Measurements were taken at the highest possible magnification using an ocular graticule.

Terminology and mensuration mostly follow Chamberlin (1931), with the exception of the nomenclature of the pedipalps, legs and with some minor modifications to the terminology of the trichobothria (Harvey 1992), chelicera (Judson 2007) and faces of the appendages (Harvey et al. 2012). Morphological characters were scored using Open DELTA 1.0 (Atlas of Living Australia, Canberra, Australia) (Dallwitz et al. 1999 onwards), which was also used to generate a natural language description that was subsequently edited further.

Family Atemnidae Kishida, 1929

Subfamily Atemninae Kishida, 1929

Genus *Anatemnus* Beier, 1932

Anatemnus Beier 1932: 578.

TYPE SPECIES

Chelifer javanus Thorell, 1883, by original designation.

REMARKS

The genera of Atemninae are, in general, poorly defined and in need of reassessment and revision (Klausen 2005). Some of the features used by Beier (1932a, 1932b) when the generic classification was first established have since been shown to be of dubious utility. For example, *Titanatemnus* Beier, 1932 was separated from other genera mainly by its large size, and *Catatemnus* Beier, 1932, *Metatemnus* Beier, 1932, *Stenatemnus* Beier, 1932, and *Tamenus* Beier, 1932 were segregated from the other atemnine genera by the presence of a transverse furrow on the carapace (Beier 1932b). Klausen (2005) has since suggested that the presence of a furrow has been frequently misinterpreted in atemnids and is of dubious usefulness to separate genera.

The new species described below, as well as *O. cavernicola* from New South Wales, have trichobothria *it* and *isb* widely spaced, with *it* either midway between *isb* and the tip of the finger, or with *it* closer to the tip than to *isb*. Only a few genera of Atemninae have species with this configuration including some species of *Anatemnus* Beier, 1932 and *Catatemnus* Beier, 1932, and all species of *Mesatemnus* Beier and Turk, 1952, *Metatemnus* Beier, 1932, *Stenatemnus* Beier, 1932, *Synatemnus* Beier, 1944 and *Tamenus* Beier, 1932 (e.g. Beier 1932b; Vachon 1938; Beier 1944, 1951a, 1951b; Beier and Turk 1952; Beier 1957, 1965; Muchmore 1972; Mahnert 1978). We suggest that this feature might be of some value in diagnosing genera of Atemninae, and accordingly place the new species and *O. cavernicola* amongst this group of genera. Not all species of *Anatemnus* and *Catatemnus*, however, have this arrangement. For example, *A. luzonicus* Beier, 1932, *A. madecassus* Beier, 1932, *A. nilgiricus* Beier, 1932, *A. orites* (Thorell, 1889), *A. subindicus* (Ellingsen, 1910), *A. subvermiformis* Redikorzev, 1938), *A. tonkinensis* Beier, 1943, *C. braunsi* (Tullgren, 1907) and *C. comorensis* (Ellingsen, 1910) have *isb* and *it* situated adjacent to each other or with *it* only slightly distal to *isb* (e.g. Beier 1932b, 1951a). It is currently difficult, or impossible, to adequately diagnose *Mesatemnus*, with the sole species *M. cyprianus* (Beier and Turk) from Cyprus, which was poorly described (Beier and Turk 1952) and has not since been redescribed. Likewise, the African genus *Synatemnus* is poorly characterized (Beier 1944).

Our decision to include the new subterranean species and *O. cavernicola* in *Anatemnus* is clearly provisional, but there appears to be nothing in the generic descriptions that precludes their inclusion in the genus (Beier 1932a, 1932b), and we are unable to suggest an alternative generic arrangement. For example, both species lack the gaping chelal fingers that are characteristic of *Metatemnus* (Beier 1932b, 1952; Muchmore 1972), they lack the long tarsal claws of *Stenatemnus* (Beier 1932b), and they lack the extremely distal position of *it* that is found in *Tamenus*.

Likewise, due to the position of trichobothria *isb* and *it*, they are unlikely to be included in *Oratemnus*, the only other atemnid genus currently recorded from mainland Australia. However, even this is somewhat confounded as the Australian species currently placed in this genus, *O. curtus*, *O. distinctus* and *O. punctatus*, lack the narrow pedicel of the pedipalpal patella found in the type species *O. articulosus* (Simon, 1899) which was originally used to define the genus (Beier 1932a, 1932b). The narrow pedicel occurs in other Australasian species such as *O. boettcheri* Beier, 1932, *O. brevidigitatus* Beier, 1940, *O. confusus* Murthy and Ananthakrishnan, 1977, *O. manilanus* Beier, 1932, *O. proximus* Beier, 1932, *O. timorensis* Beier, 1932 and *O. yodai* Morikawa, 1968 (e.g. Beier 1932a, 1932b, 1940; Morikawa 1968; Murthy and Ananthakrishnan 1977), but is lacking in other species including *O. afghanicus* Beier, 1959, *O. semidivisus* (Redikorzev, 1938) and *O. loyolai* Sivaraman, 1980 from Asia, and *O. samoanus* Beier, 1932 from the Pacific region (e.g. Beier 1932a, 1932b; Redikorzev 1938; Beier 1948, 1954, 1959, 1976; Sivaraman 1980). To further confuse matters, it is possible that there might be slight sexual dimorphism in those species with narrow pedicels. The illustrations of *O. samaonus* by Chamberlin (1939) show the male with a slightly longer and thinner pedicel that the female, and those species with a more extenuated pedicel that were illustrated by Beier (1932b) all appear to be males rather than females.

Therefore, we attribute *A. subvastus* and *Oratemnus cavernicola* to the genus *Anatemnus*, forming the new combination *Anatemnus cavernicola* (Beier, 1976), but note that the generic assignment should be reviewed pending an assessment of all atemnine genera which are currently poorly defined and badly in need of redefinition (Klausen 2005). These are not the only Australian species of *Anatemnus*, as other species have been collected in rainforest habitats in eastern Australia (MSH, unpublished data). It is presumed that they represent undescribed species, but further work is needed on the atemnid fauna of Australia to adequately resolve their status.

Anatemnus subvastus sp. nov.

Figures 2–18

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** , Blackjack, c. 75 km NNW. Tom Price, site HPRC0426, 22°06'42.3"S, 117°24'54.4"E, 14 April–14 June 2011, subterranean trap, 40 m, D.C. Main, J.W. Quartermaine (WAM T119416)

Paratypes

Australia: ***Western Australia:*** 1 , Champion, c. 75 km NNW. Tom Price, site HPRC0553, 22°06'11.6"S, 117°27'46.2"E, 14 April 2011, stygofauna net, 22 m, J.S. Cocking, M.K. Curran (WAM T119417); 1 , c. 80 km NW. of Tom Price, bore HPRC2089, site FLI091, 22°07'52.9"S, 117°29'12.2"E, 24 June 2010, J.S. Cocking, D.C. Main (WAM T108774); 1 , Homestead, 77.7 km NNW. of Tom Price, bore RHWRC0249P1-1, 22°04'42"S, 117°25'31"E, 29 January 2010, scraping borehole, G. Humphreys (WAM T102542).

DIAGNOSIS

Anatemnus subvastus differs from all other species of the genus, except *A. cavernicola*, by the lack of eye-spots. It differs from *A. cavernicola* by the size and shape of the pedipalps, with *A. subvastus* with a pedipalpal femur length of 0.59–0.71 ( ), 0.64 ( ) mm, and *A. cavernicola* of 1.25 ( ) mm.

DESCRIPTION

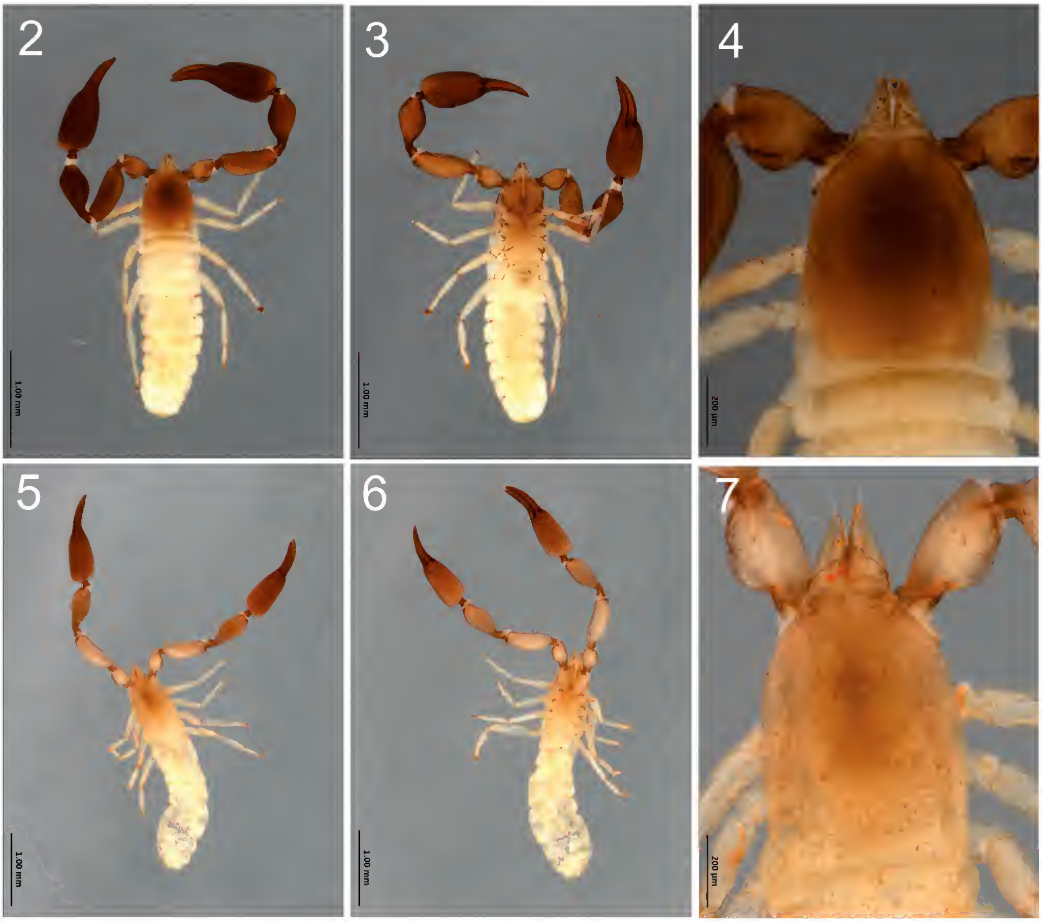
Adults

Colour (Figures 2–7): carapace and pedipalps dark red-brown; coxae red-brown; abdomen and legs pale yellow-brown.

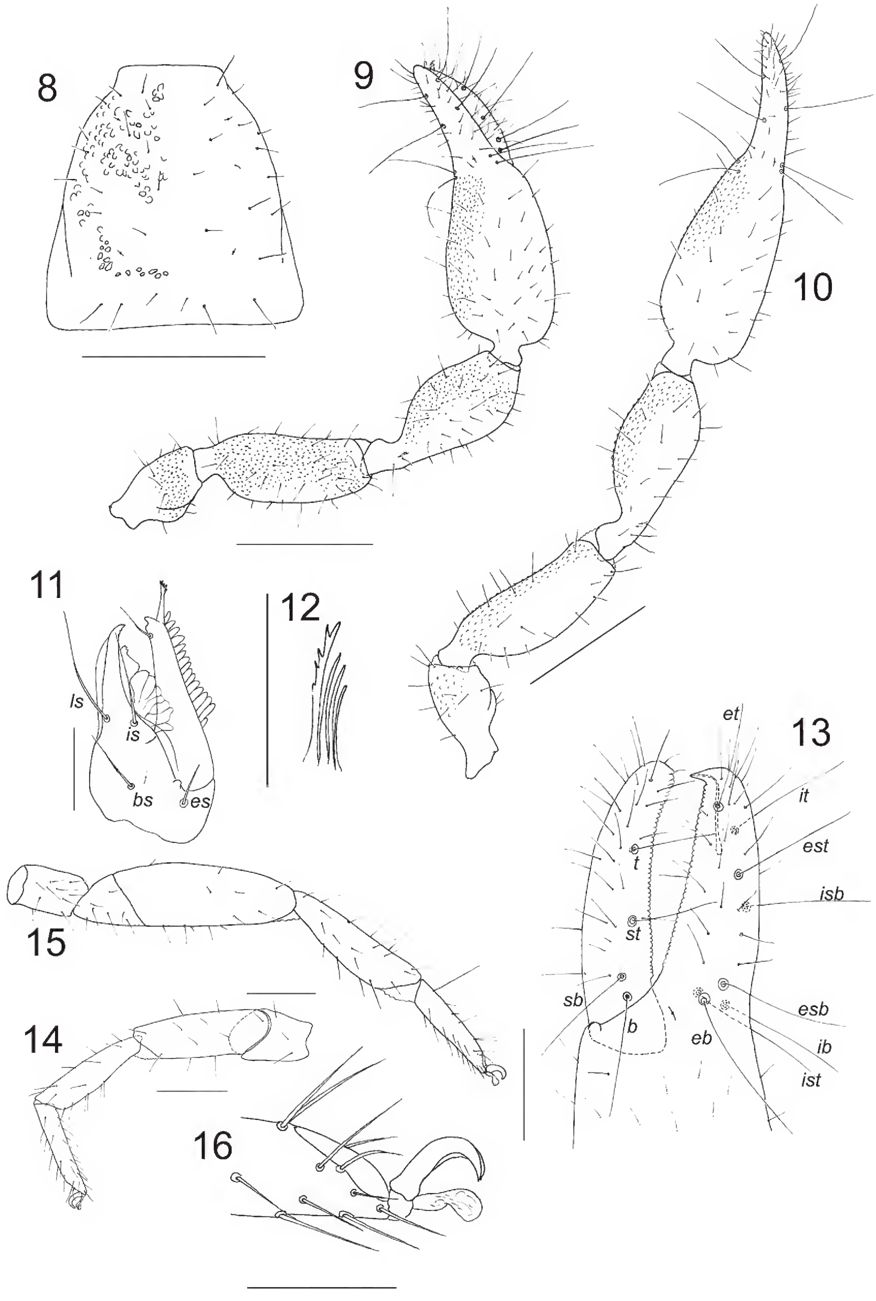
Setae and cuticle: setae long, mostly straight and acicular; most cuticular surfaces smooth and glossy, with exception of pedipalps, which are finely granulate.

Chelicera (Figure 11): much smaller than carapace length; surface smooth; cheliceral hand with 4 setae (*sbs* absent); movable finger with 1 sub-distal seta; all setae acuminate; seta *bs* shorter than others; galea present, with several distal to sub-distal rami; with 2 dorsal and 1 ventral lyrifissures present; exterior condylar lyrifissure situated near exterior condyle; serrula interior connected to the cheliceral fixed finger for entire length, proximally modified to form velum; serrula exterior with 16 ( ), 17 ( ) blades; lamina exterior present; rallum (Figure 12) with 4 blades, first two blades with anterior spinules, remainder smooth; rallum with basal and sub-basal blades shorter than others.

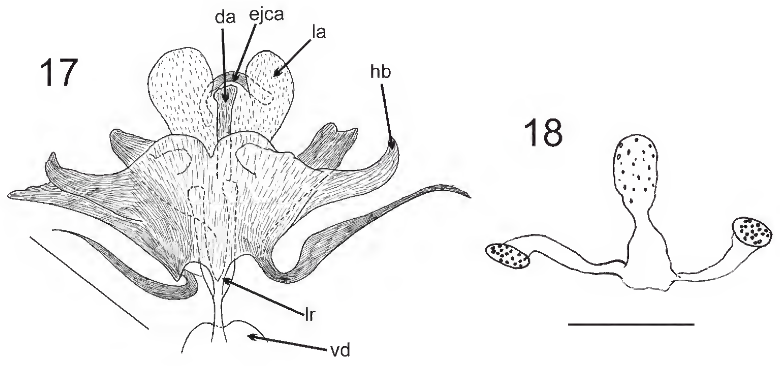
Pedipalps (Figures 9, 10): stout; lightly granulate on femur, patella, and at base of chelal fingers on prolateral face; setae acicular, straight or nearly so; trochanter with anterior margin rounded, with unmodified dorsal tubercle, 1.66–1.78 ( ), 1.79 ( ) x; femur cylindrical, robust, with 1 small trichobothrium on dorsal surface, situated near basal margin, 2.62–2.97 ( ), 2.72 ( ) x; patella cylindrical, robust, with narrow pedicel, with several small lyrifissures situated basally on dorsal surface, 2.11–2.44 ( ), 2.58 ( ) x; chelal hand cylindrical, external and internal chelal condyles small and rounded, chela (with pedicel) 2.97–3.21 ( ) longer than broad, 3.55 ( ) x, chela (without pedicel) 2.78–2.96 ( ), 3.38 ( ) x; hand (without pedicel) 1.50–1.84 ( ), 2.03 ( ) x;



FIGURES 2–7 *Anatemnus subvastus* sp. nov.: 2–4, male holotype (WAM T119416): 2, body, dorsal; 3, body, ventral; 4, carapace, dorsal; 5–7, female paratype (WAM T119417): 5, body, dorsal; 6, body, ventral; 7, carapace, dorsal.



FIGURES 8–16 *Anatemnus subvastus* sp. nov., male holotype (WAM T119416), unless stated otherwise: 8, carapace, dorsal; 9, right pedipalp, dorsal; 10, right pedipalp, dorsal, female paratype (WAM T119417); 11, right chelicera, dorsal; 12, rallum; 13, left chelal fingers, lateral; 14, left leg I, lateral; 15, left leg IV, lateral; 16, tip of tarsus IV, lateral. Scale lines = 0.5 mm (Figures 8–10), 0.2 mm (Figure 13), 0.2 mm (Figures 14–15), 0.1 mm (Figures 11–12, 16).



FIGURES 17–18 *Anatemnus subvastus* sp. nov.: 17, genitalia, ventral, male holotype (WAM T119416); 18, genitalia, ventral, female paratype (WAM T119417). Abbreviations: da, dorsal apodeme; ejca, ejaculatory canal atrium; hb, hooked branches; la, lateral apodemes; lr, lateral rod; vd, ventral diverticulum. Scale lines = 0.1 mm.

movable finger 0.75–0.95 ( ), 0.68 ( ) x longer than hand (without pedicel). Fixed finger with 8 trichobothria; movable finger with 4 trichobothria (Figure 13); *eb* and *esb* situated at base of fixed finger on retrolateral face; *ib* and *ist* situated at base of fixed finger on prolateral face; *isb* slightly proximad to *est*; *it* midway between *et* and *est*; *et* slightly distad to *it*; *sb* much closer to *b* than to *st*; *st* midway between *sb* and *t*; *t* acuminate. Both fingers straight in lateral view; chelal teeth juxtadentate; fixed finger with 37 ( ), 42 ( ) rounded teeth; movable finger with 46 ( ), 49 ( ) rounded teeth; accessory chelal teeth absent; venom apparatus present only in fixed chelal finger; venom duct long, terminating in nodus ramosus between *et* and *est*; nodus ramosus inflated; sense spots absent.

Cephalothorax: carapace (Figure 8) sub-rectangular; anterior margin medially indented; epistome absent; lateral margins evenly convex; 1.29–1.37 ( ), 1.36 ( ) x longer than broad, with 23–25 ( ), 23 ( ) setae including 4 on anterior margin and 4 on posterior margin; furrows absent; eyes absent. Manducatory process somewhat pointed, with 2 apical setae and 1 sub-oral seta; maxilla with 20 ( ), 16 ( ) other setae; maxillary shoulder absent; median maxillary lyrifissure present, situated medially, strongly curved, U-shaped; posterior maxillary lyrifissure present, strongly curved. Coxa I about same width as coxa IV; coxae I-IV setal formula: , 8: 6: 5: 10; , 7: 7: 5: 14.

Legs (Figures 14, 15): femora I and II about same size as patellae I and II, respectively; junction between anterior femora and patellae oblique; junction between posterior femora and patellae strongly angulate; femora III and IV much smaller than patellae III and IV, respectively; femur + patella IV 3.48–3.86 ( ), 4.14 ( ) x longer than broad; tibiae III and IV without tactile seta; tarsi III and IV with long tactile seta, situated basally; tarsal lyrifissure lying flush with tarsal surface; subterminal tarsal seta curved; claws smooth; arolium slightly shorter than claws; arolium not divided (Figure 16).

Abdomen: tergites straight; not divided; tergites, setal formula , 6: 6: 6: 9: 10: 8: 9: 10: 11: 13: 12: 2; , 5: 4: 6: 7: 8: 9: 8: 8: 10: 12: 15: 2; arranged in single rows; lateral margin of tergites not modified; sternites, setal formula , 11: (1) 6 (1): (1) 6 (1): 9: 9: 10: 10: 10: 10: 13: 2; sternites, setal formula , 11: (1) 7 (1): (1) 6 (1): 10: 10: 9: 10: 10: 11: 13: 2; glandular setae absent; medial sternites without suture line; pleural membrane uniformly longitudinally striate; without setae; stigmatic helix present; anus (tergite XII and sternite XII) without raised rim; anus situated between tergite XI and sternite XI.

Genitalia: male: dorsal apodeme long with rounded apex, ejaculatory canal atrium broad, lateral apodemes spherical, lateral rods Y-shaped with rounded apices, hooked branches wide (Figure 17), genital atrium without glandular setae; female (Figure 18): with single anteriorly directed spermathecal lobes, and 1 pair of small lateral cribriform plates.

Dimensions (mm): Males: holotype followed by other males (where applicable): Body length 2.58 (2.24–2.66). Chelicera 0.241/0.152; movable finger length 0.195. Pedipalp: trochanter 0.385/0.218 (0.371–0.382/0.215–0.223); femur 0.652/0.248 (0.589–0.712/0.225–0.240); patella 0.650/0.289 (0.637–0.662/0.271–0.302); chela (with pedicel) 1.139/0.382 (1.132–1.162/0.362–0.381); chela (without pedicel) length 1.066 (1.058–1.072); chelal hand (without pedicel) length 0.704 (0.573–0.595);

movable finger length 0.531 (0.470–0.542). Carapace 0.715/0.543 (0.710–0.742/0.518–0.576). Leg I: femur 0.228/0.144; patella 0.376/0.127; tibia 0.323/0.084; tarsus 0.296/0.052. Leg IV: femur + patella 0.637/0.183 (0.571–0.618/0.153–0.160); tibia 0.458/0.118; tarsus 0.309/0.072.

Female: paratype (WAM T119417): Body length 2.83. Chelicera 0.261/0.133; movable finger length 0.185. Pedipalp: trochanter 0.377/0.211; femur 0.642/0.236; patella 0.680/0.264; chela (with pedicel) 1.264/0.356; chela (without pedicel) 1.208; hand (without pedicel) 0.724; movable finger length 0.495. Carapace 0.778/0.572. Leg I: femur 0.212/0.123; patella 0.353/0.097; tibia 0.328/0.051; tarsus 0.295/0.049. Leg IV: femur + patella 0.633/0.153; tibia 0.459/0.085; tarsus 0.315/0.063.

REMARKS

Anatemnus subvastus has been collected from a very small area of the central Pilbara in the Hamersley Range, less than 20 km^2. All four specimens were collected from subterranean environments either using baited subterranean fauna traps, or by scraping the sides of the boreholes with a net. The specimens lack eye spots and are notably paler than epigean species of the genus (M. Burger, M. Harvey, personal observations). There is some notable variation in the size and proportions of the pedipalps and legs between the samples collected. For example, the pedipalpal femur is 0.59–0.71 ( ), 0.64 ( ) mm in length and 2.62–2.97 ( ), 2.72 ( ) x longer than broad, the pedipalpal patella is 0.64–0.66 ( ), 0.68 ( ) mm in length and 2.11–2.44 ( ), 2.58 ( ) x longer than broad, and the chela (without pedicel) is 1.13–1.16 ( ), 1.21 ( ) mm in length and 2.78–2.96 ( ), 3.38 ( ) x longer than broad. However, as the specimens come from a small area, we prefer to attribute this to intraspecific variation.

This species represents only the second troglobitic species of the genus. The first, *A. cavernicola*, from Jump Up Cave, in the Grey Range in north-western New South Wales, is substantially larger than *A. subvastus*, with a pedipalpal femur length of 1.25 mm (Beier 1976).

The subterranean fauna of the immediate area contains several other confirmed troglobites, including undescribed species of *Draculoides* and *Paradraculoides* (Schizomida, Hubbardiidae), *Lagynochthonius* and *Tyrannochthonius* (Pseudoscorpiones, Chthoniidae), Dalodesmidae (Diplopoda, Polydesmida) (C.A. Car, personal communication) and *Cormocephalus* (Scolopendrida, Scolopendridae) (J.M. Waldock, personal communication).

ETYMOLOGY

The species name refers to the presence of this species in subterranean environments in the semi-arid Pilbara region of Western Australia (*sub-*, Latin, under; *vastus*, Latin, waste, desert).

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Two new species of peacock spider of the *Maratus mungaich* species-group (Araneae: Salticidae) from south-western Australia

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ABSTRACT – Following the redefinition of the Banksia Peacock Spider, *Maratus mungaich*, and the recognition of four related species in the *M. mungaich* species-group, two more new species can be added to this group: *Maratus hortorum* sp. nov. was previously misidentified as *M. mungaich* Waldock, 1995 but it is here recognised as a distinct species; and *M. madelineae* sp. nov. has been found occurring in the gap created by the reduced distribution of *M. mungaich* and the five more southern species (*M. karrie* Waldock, 2013, *M. melindae* Waldock, 2013, *M. sarahae* Waldock 2013, *M. caeruleus Waldock*, 2013, and *M. avibus* Otto and Hill, 2014a). These new species are herewith described.

KEYWORDS: taxonomy, morphology, south-western Western Australia

INTRODUCTION

The jumping spider genus *Maratus* Karsch, 1878 is endemic to the Australian region, and currently includes 49 described species (Otto and Hill 2014d; World Spider Catalog 2014). The males of most species have brightly coloured abdomens which have lateral flaps that are inflated during courtship displays with females (Figures 10, 20). Males of many species also have enlarged, setose third legs which are used in the complex display performance (Figure 10). The *M. mungaich* species-group (see Waldock, 2013; Otto and Hill, 2014a) is one of the most distinctive assemblages within the genus, and is restricted to south-western Western Australia where five species are currently recognised. These include *M. mungaich* Waldock, 1995, *M. karrie* Waldock, 2013, *M. melindae* Waldock, 2013, *M. sarahae* Waldock, 2013, *M. caeruleus* Waldock, 2013 and *M. avibus* Otto and Hill, 2014a. Males of this group possess a colour pattern of alternate transverse red stripes on the dorsal abdominal surface (Waldock 2013; Otto and Hill 2014a).

Eight male specimens of *Maratus* collected from Talbot Road Reserve (now known as Talbot Road Regional Reserve) in the 1990s were previously identified as *M. mungaich* (Waldock 1995, 2013) but further recent collections from this site and reassessment of earlier collections have revealed additional specimens which confirm this as a unique species, described in this paper as *M. hortorum* sp. nov. In addition, recent collections near Dardanup have revealed a further undescribed species from the south-west forests mid-way between the known ranges of *M. mungaich* (which extends north to Toodyay, south to Mt Cooke, and east to Darkin Road) (Waldock 1995), and those of the southern species, *M. karrie*, *M. melindae*, *M. sarahae*, *M. caeruleus* and *M. avibus* (Waldock 2013; Otto and Hill 2014a).

MATERIAL AND METHODS

The material examined for this study is lodged in the Western Australian Museum, Perth, Australia (WAM). Specimens were preserved and described in 75% or 100% ethanol, illuminated with Halogen lights, and illustrated with the abdomen and cephalothorax in a flat, horizontal position. Female genitalia were examined by dissecting epigynes and clearing them in 10% lactic acid overnight. Epigynes were mounted in glycerol and illustrated with a camera lucida on a Leica DM 2500 compound microscope. Other drawings and measurements were made using a Leica MS5 or Leica MZ16A stereo microscope and Leica Application Suite V3.8.0 from Leica Microsystems Ltd.

http://www.zoobank.org/urn:lsid:zoobank.org:pub:25AABA79-487B-437B-8487-C359774651A4

TAXONOMY

Family Salticidae Blackwall, 1841

Subfamily Euophryinae Simon, 1901

Genus *Maratus* Karsch, 1878

Maratus Karsch 1878: 27.

TYPE SPECIES

Maratus amabilis Karsch, 1878, by subsequent designation of Bonnet (1957: p. 2713).

COMPOSITION

Twenty-four described species – *Maratus amabilis* Karsch, 1878, *M. avibus* Otto and Hill, 2014a, *M. caeruleus* Waldock, 2013, *M. calcitrans* Otto and Hill, 2012c, *M. clupeatus* Otto and Hill, 2014c, *M. digitatus* Otto and Hill, 2012c, *M. harrisi* Otto and Hill, 2011, *M. karrie* Waldock, 2013, *M. leo* Otto and Hill, 2014d, *M. linnaei* Waldock, 2008, *M. literatus* Otto and Hill, 2014d, *M. maritimus* Otto and Hill, 2014d, *M. melindae* Waldock, 2013, *M. montanus* Otto and Hill, 2014d, *M. mungaich* Waldock, 1985, *M. pardus* Otto and Hill, 2014b, *M. pavonis* (Dunn, 1947), *M. plumosus* Otto and Hill, 2013, *M. sarahae* Waldock, 2013, *M. speciosus* (O.P.-Cambridge, 1874), *M. rainbowi* (Roewer, 1951), *M. tasmanicus* Otto and Hill, 2013, *M. vespertilio* (Simon, 1901), *M. volans* (O.P.-Cambridge, 1874), *M. watagansi* Otto and Hill, 2013 – and at least 15 undescribed species (Waldock, unpublished data). However, Otto and Hill (2012b) synonymised *Lycidas* Karsch, 1878 (type species *L. anomalus* Karsch, 1878) with *Maratus*, greatly expanding the limits of the latter genus and taking the total number of described species to 49.

REMARKS

The specific (and often spectacular) colour patterns on male *Maratus* species are the result of specialised short squamous setae, which cover the dorsal abdominal scute and parts of the dorsal carapace (Figures 10, 20, 21, 22). These setae reflect different colours depending on the angle of orientation and also reflect different colour spectra on different parts of the abdomen (Figures 21, 22).

When preserved in alcohol, the vibrancy of the colours may be reduced, e.g. squamous setae that appear red in life will show as orangey to light brown over time. To standardise the colour pattern descriptions, the specimens were viewed under Halogen lights with the abdomen and cephalothorax in a flat, horizontal position. This combination leads to the squamous setae reflecting colours as rose-gold, orangey, brown and pink. When the abdomen is raised to a vertical position the rose-gold squamous setae reflect as electric blue; in life these rose-gold coloured areas are blue-green.

To simplify the descriptions the stripes that are red in life (i.e. orangey to light brown in ethanol) are stippled and termed as A, B and C (Figures 1, 11) and the anterior and posterior extensions from these main stripes are called 'arms' (see Figure 22).

Maratus madelineae sp. nov.

Madeline's Peacock Spider

Figures 1–10

http://www.zoobank.org/urn:lsid:zoobank.org:act:0677326E-A36D-4E45-A6C3-56525CC7E9DF

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia***: , Dardanup National Park, 33°25'04.2"S, 115°48'36.9"E, 26 September 2013, M.B. Girard, D.O. Elias, J.M. Waldock (WAM T130294).

Paratypes

Australia: ***Western Australia***: 3 , same data as holotype (WAM T131966–8); 2 , same data as holotype (WAM T132135–6).

DIAGNOSIS

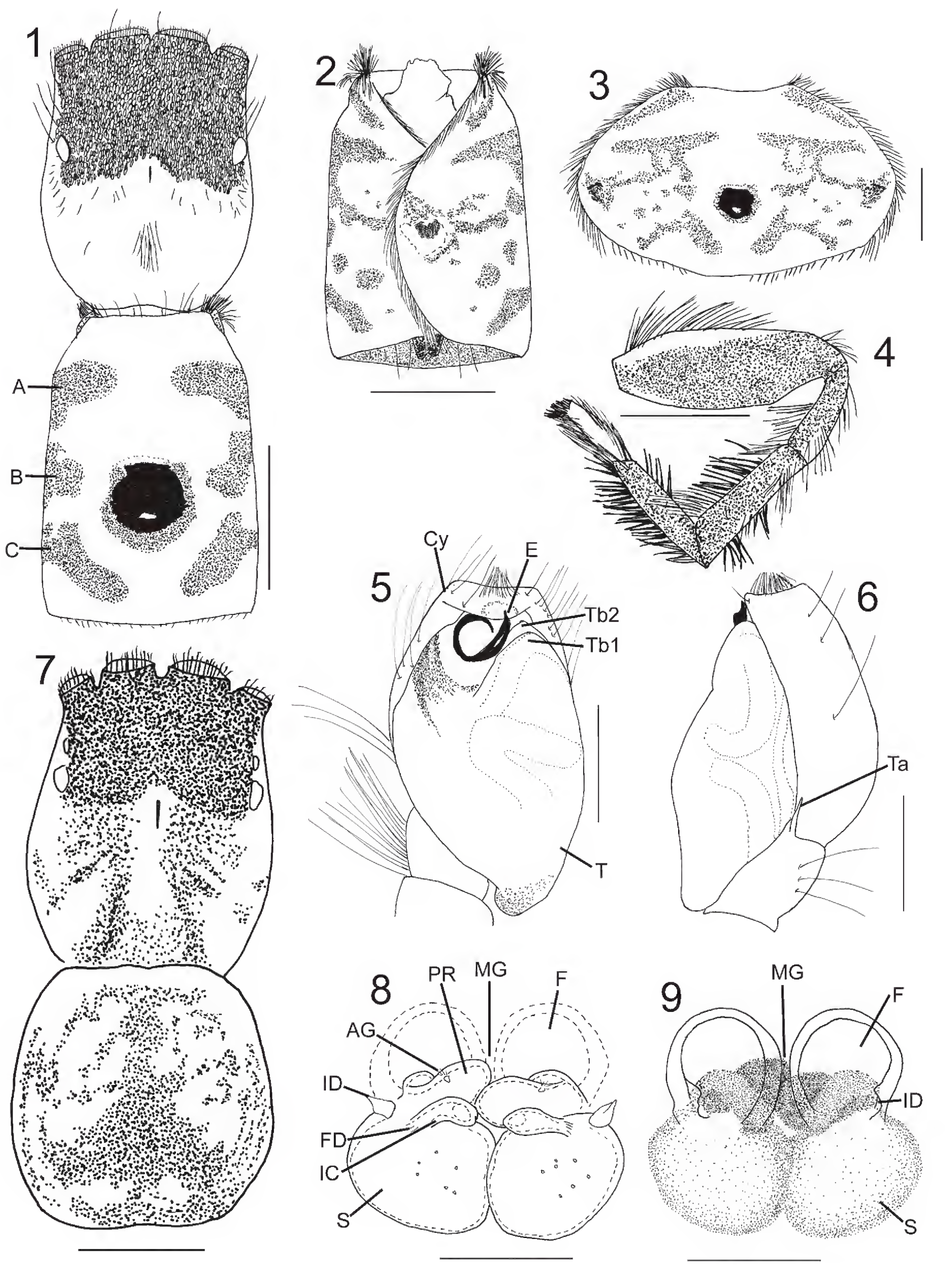
Males of *Maratus madelineae* can be distinguished from all other species in the *M. mungaich* species-group by the presence of a broad rather than a narrow stripe C dorsally; by the small, circular central black patch almost encircled by red; and by the discontinuous dorsal abdominal stripes A, B and C, with stripe B fragmented and with branches linking to stripe A. This species can be further distinguished by the presence of a glossy blue-black patch on each abdominal flap (Figures 3, 10), and by the setation of leg III, with black brushes on all segments and distinctive white bristles in clumps on the femur, patella and tibia (Figures 4, 10).

DESCRIPTION

Male (holotype)

Cephalothorax black to dark brown with white hairs bordering lateral edges. Dense mat of light orange squamous setae covering ocular region; oval patch of white hairs posterior to fovea. Anterior eyes fringed with creamy hairs along dorsal margin; rest of cephalothorax lightly covered with scattered short white hairs and brown bristles (Figure 1). Clypeus yellowy-brown, chelicerae dark brown, cream distally. Maxillae light cream, labium dark grey with cream edge. Sternum dark grey.

Venter of abdomen dark yellow with greyish smudges in centre and laterally; spinnerets black. Dorsal abdominal scute developed as lateral flaps which fold over each other ventrally, but extendable laterally to exhibit a continuation of dorsal pattern (Figures 3, 10). Stripe A of red-orange squamous setae present, extending as broad band from the flaps but not continuous across dorsum. Stripe B of red-orange also broad extending posteriorly on sides of abdomen, on dorsum disjointed, not reaching central black patch. Circular central black patch with a



FIGURES 1–9 *Maratus madelineae* sp. nov., male holotype (WAM T130294): 1, cephalothorax and abdomen, dorsal view; 2, abdomen, ventral view (abdominal flaps folded); 3, abdomen extended from image in Figure 10; 4, left leg III, prolateral view; 5, left pedipalp, ventral view; 6, left pedipalp, retrolateral view. Female paratype (WAM T132135): 7, cephalothorax and abdomen, dorsal view; 8, cleared epigyne (WAM T132136), dorsal view; 9, epigyne (WAM T132136), ventral view. Scale lines = 1 mm (Figures 1, 2, 3, 4, 7), 0.5 mm (Figures 5, 6), 0.25 mm (Figures 8, 9). A, B, C = red transverse stripes A-C; AG = accessory gland; Cy = cymbium; E = embolus; T = tegulum; TA = tibial apophysis; TB1–2 = tegular bulges 1–2; AG = accessory gland; F = fossa; FD = fertilisation duct; IC = intermediate canal; ID = insemination duct; MG = median guide; PR = proximal receiver; S = spermatheca.

FIGURE 10 *Maratus madelineae* sp. nov., male from Dardanup National Park, Western Australia, 26 September 2013 with expanded abdominal flaps, displaying for female. (Image courtesy Madeline Girard.)

very narrow light blue strip anteriorly and with small light blue spot off-centre to posterior, band of red-orange surrounds black patch except along anterior edge where light blue strip occurs (Figures 1, 10). Stripe C dissected into red-orange patches of squamous setae laterally, directed posteriorly below central black patch extending onto flaps (Figures 1, 10). Anterior corners of abdomen with stiff orange and black bristles. Stiff long cream and brown bristles projecting from anterior border of abdomen (Figure 1). Lateral flaps with blue-black circular 'eye' patch anteriorly near edge of flap; 'eye' patch almost entirely encircled with red-orange anteriorly (stripe B), remainder of flaps rose-gold and bright blue. Stripes A, B and C extend from dorsum onto flaps; stripe B reaches edge of flap; anterior edge of flap with broad red-orange elongate strip (Figures 3, 10). Long black or dark brown hairs bordering anterior edge of flaps, long creamy hairs laterally (Figures 2, 3).

Legs I, II and IV: proximal femora cream dorso-anteriorly with dark grey patches ventro-posteriorly; patellae, tibiae, metatarsi and tarsi yellow with grey bands at joints; covered with dense short white hairs interspersed with black bristles. Leg III: proximal dorsal femur cream, rest dark grey dorsally and ventrally, patella and tibia dark grey except for light orange dorsal stripe, metatarsus grey, tarsus cream. Patella and tibia III with thick brush hairs dorso-ventrally, brush hairs in bunches of black and white (Figure 10); metatarsus III with thick brush of dark grey hairs, dorso-ventrally; tarsus III with thick short white hairs on all surfaces and longer white hairs at tip, covering claws (Figures 4, 10).

Pedipalp creamy yellow with scattered greyish patches distally. Tibial apophysis narrow, straight (Figure 6). Cymbium, dorsal tibia and dorsal patella densely covered with long white hairs, a single very long black hair on dorsal pedipalpal patella; tibia and cymbium with a few long creamy and brown hairs on ventral side just under tegulum. Embolus with conductor closely aligned into tight coil, tucked under tip of cymbium; tegulum with two bulges adjacent to embolus (Figure 5).

Female (paratype, WAM T132136)

Ocular region black, densely covered with short black and creamy hairs, rest of cephalothorax yellowish-grey grading to light yellow towards posterior with scattered black hairs. Posterior to ocular area and fovea, dark grey; two broad grey bands extend to posterior margin with light yellow central strip (Figure 7). Sides of cephalothorax greyish-yellow. Clypeus light yellow; chelicerae, maxillae, labium light yellow with white border. Sternum cream with light grey edging.

Abdomen oval with tan dorsal sigillae and black bristles scattered amongst brown and creamy hairs; most of dorsum covered in greyish diffuse pattern on creamy background; pattern darkens and narrows to point above spinnerets (Figure 7). Venter of abdomen cream, with small grey spots in longitudinal rows, larger spots at edges. Ventral spinnerets light grey, dorsal pair dark grey.

Femora and patellae of legs creamy, no markings dorsally, grey patches at joints and mid-way of femora; tibiae, metatarsi and tarsi yellowy with grey bands at joints.

Proximal receivers of epigyne large and abutting each other at median guide. Intermediate canals resting on spermathecae, openings directed off-centre of anterior of spermathecae. Insemination ducts opening centrally above anterior portion of spermathecae (Figures 8, 9).

Dimensions (mm)

Holotype (paratype , WAM T132136*)*: total length excluding chelicerae 6.98 (8.86). Carapace length 3.30 (3.75). Abdomen length 3.68 (4.52). Leg I: femur 1.52 (1.50), patella 0.94 (0.92), tibia 0.74 (0.78), metatarsus 0.72 (0.61), tarsus 0.55 (0.62). Leg II: femur 1.31 (1.68), patella 1.14 (1.16), tibia 0.72 (0.76), metatarsus 0.74 (0.55), tarsus 0.54 (0.56). Leg III: femur 2.72 (2.47), patella 0.88 (0.96), tibia 1.45 (1.48), metatarsus 1.12 (1.18), tarsus 0.74 (0.76). Leg IV: femur 1.90 (1.79), patella 0.86 (1.08), tibia 1.06 (1.25), metatarsus 1.47 (1.11), tarsus 0.63 (0.86). Legs, relative lengths: III: IV: I: II (III: IV: II: I).

VARIATION

The additional males and females differ little from the holotype male and paratype female described above.

DISTRIBUTION

Maratus madelineae has only been recorded from Dardanup National Park in *Banksia*, jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) woodland.

ETYMOLOGY

The specific epithet is a patronym in honor of Madeline Girard, enthusiastic researcher uncovering the wonders of the complex behaviours of these fascinating spiders.

Maratus hortorum **sp. nov.**

Hort's Peacock Spider

Figures 11–22

http://www.zoobank.org/urn:lsid:zoobank.org:act:D83CC4D6-4311-41D8-B296-5EF0436222AF

Maratus mungaich Waldock, 1995: 167 (in part, misidentification of specimens from Talbot Road Reserve); Otto and Hill, 2012a: 1, figure 7(4); Otto and Hill, 2014a: 13, figure 17(2) (references to specimens from Talbot Road Nature [sic.] Reserve).

MATERIAL EXAMINED

Holotype

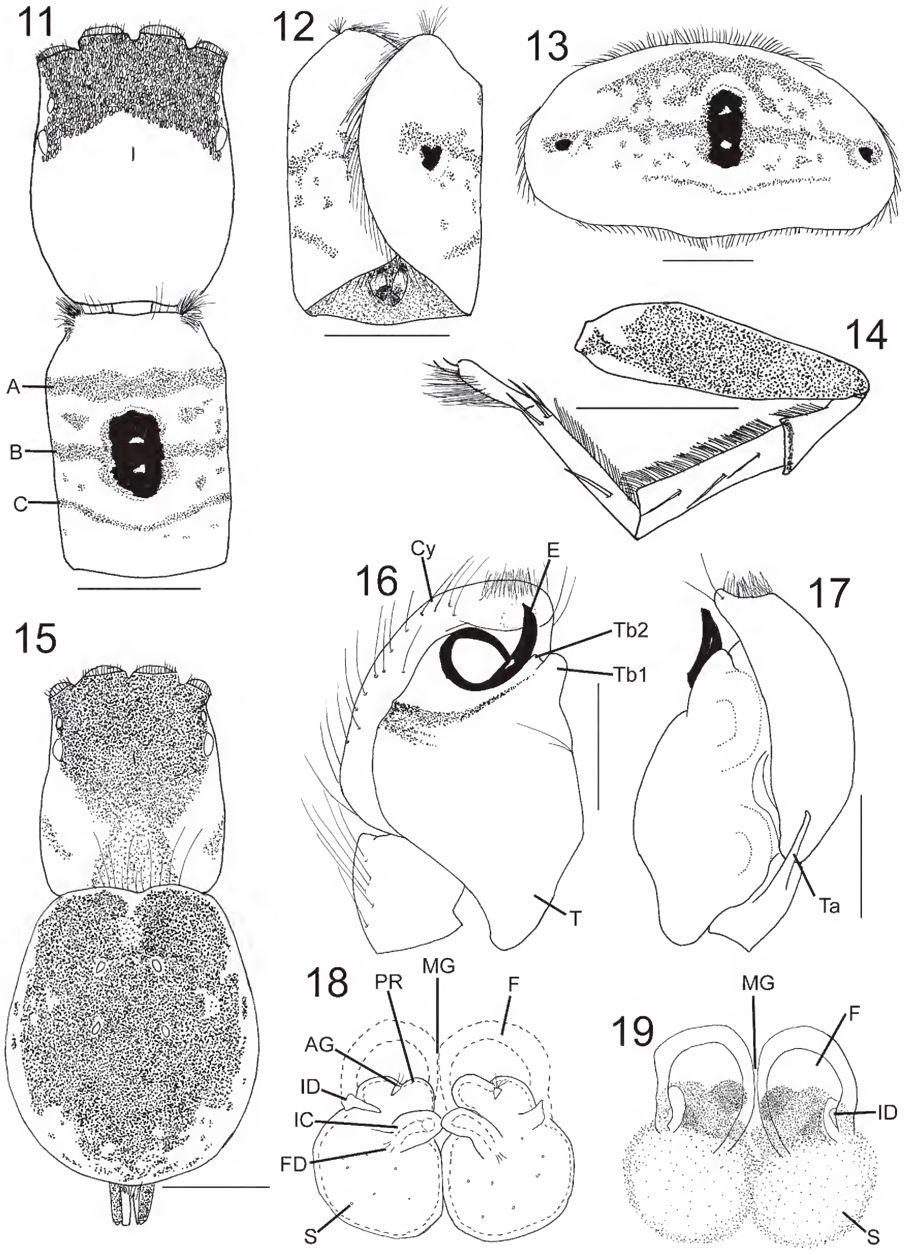
Australia: ***Western Australia*****:** , Stratton, Talbot Road Regional Reserve, 31°52'22.8"S, 116°02'39.8"E, 13 August 2014, open *Banksia* woodland, F. Hort, J. Hort (WAM T133826).

Paratypes

Australia: ***Western Australia*****:** 1 , same data as holotype (WAM T133827); 1 , Talbot Road Reserve, site 1, 31°52'05"S, 116°03'04"E, 28 July 1993, J.M. Waldock, A. Sampey (WAM 93/1650); 1 , 1 juvenile, Talbot Road Reserve, site 1, wet pitfalls, 31°52'05"S, 116°03'04"E, 10 May–24 June 1993, M.S. Harvey, J.M. Waldock (WAM 93/2336-7); 3 , 1 juvenile, Talbot Road Reserve, site 1, wet pitfalls, 31°52'05"S, 116°03'04"E, 24 June–28 July 1993, M.S. Harvey, J.M. Waldock, A. Sampey (WAM 93/2338-41); 3 , 1 , Talbot Road Reserve, site 4, wet pitfalls, 31°52'23"S, 116°02'46"E, 24 June–28 July 1993, M.S. Harvey, J.M. Waldock, A. Sampey (WAM 93/2342–5).

DIAGNOSIS

Males of *Maratus hortorum* can be distinguished from all other species in the *M. mungaich* species-group by the presence of two light blue patches within a central, rectangular patch on the dorsal abdomen (Figures 11, 20–22); by the presence of a very small, central black patch almost encircled by red on each abdominal flap; and by the continuous dorsal abdominal stripes A and C, with stripe B extending to central black patch and with branches bordering black patch. This species can further be distinguished by the presence of an electric blue and black patch on each abdominal flap (Figures 13, 20), and by the setation of leg III, with black brushes ventrally on all segments except the tibia and tarsus (Figure 14), and tarsus III with a white brush of long hairs dorsally. Females of *M. hortorum* differ from *M. mungaich* by the foreshortened proximal receivers that do not meet across the median guide (Figures 18, 19) and by the presence of a solid dark patch on the dorsal surface of the abdomen (Figure 15).



FIGURES 11–19 *Maratus hortorum* sp. nov., male holotype (WAM T133826): 11, cephalothorax and abdomen, dorsal view; 12, abdomen, ventral view (abdominal flaps folded); 13, abdomen extended (WAM 93/2342); 14, left leg III, prolateral view; 16, left pedipalp, ventral view; 17, left pedipalp, retrolateral view. Female paratype (WAM T133827): 15, cephalothorax and abdomen, dorsal view; 18, cleared epigyne, dorsal view; 19, epigyne, ventral view. Scale lines = 1 mm (Figures 11, 12, 13, 14, 15), 0.5 mm (Figures 16, 17), 0.25 mm (Figures 18, 19). A, B, C = red transverse stripes A-C; AG = accessory gland; Cy = cymbium; E = embolus; T = tegulum; TA = tibial apophysis; TB1-2 = tegular bulges 1-2; AG = accessory gland; F = fossa; FD = fertilisation duct; IC = intermediate canal; ID = insemination duct; MG = median guide; PR = proximal receiver; S = spermatheca.

DESCRIPTION

Male (holotype)

Cephalothorax black to dark brown with white hairs bordering lateral edges. Dense mat of light orange squamous setae covering ocular region; no white hairs evident in patch posterior to fovea. Anterior eyes fringed with orangey hairs along dorsal margin; rest of cephalothorax lightly covered with scattered short white hairs and dark brown bristles (Figure 11). Clypeus yellowy-brown, chelicerae dark brown, cream distally. Maxillae light cream, labium dark grey with cream edge. Sternum dark grey.

Venter of abdomen dark yellow with greyish smudges in centre and laterally; distal tips of spinnerets black, rest cream (Figure 12). Dorsal abdominal scute developed as lateral flaps which fold over each other ventrally, but extendable laterally to exhibit a continuation of dorsal pattern (Figures 13, 20). Stripe A of red-orange squamous setae present as a broad, continuous band across dorsum, not extending onto lateral flaps (Figures 11, 12, 13, 20). Stripe B of red-orange, narrower than stripe A, reaching central black patch, with arms extending anteriorly and posteriorly to almost surround central black patch. Stripe B continues onto lateral flaps almost to edge bordering electric blue/black 'eye' near middle of lateral flap (Figures 11, 12, 13, 20). Rectangular central black patch with a very narrow light blue strip anteriorly and with two small light blue spots in centre to anterior and posterior (Figures 11, 13, 20). Stripe C narrow, continuous across dorsum, extending almost to edges of lateral flaps (Figures 11,

FIGURE 20 *Maratus hortorum* sp. nov., male from Talbot Road Regional Reserve, Western Australia, 16 August 2012 with expanded abdominal flaps, displaying for female. (Image courtesy F. Hort, J. Hort.)

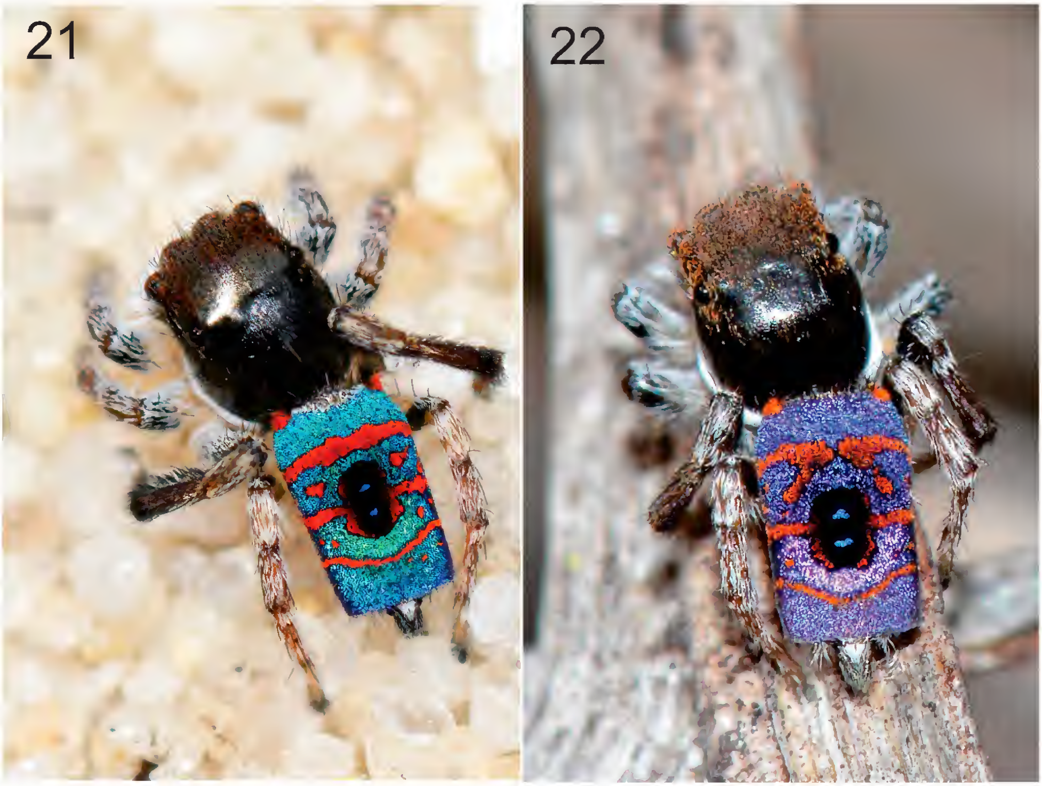
12, 13, 20). A large red-orange patch on dorsum between stripes A and B on either side of central black patch (see note below on variation) (Figures 11, 21). Two small red-orange patches on dorsum between stripes B and C on either side of central black patch. Anterior corners of abdomen with stiff orange and black bristles. Stiff long cream and brown bristles projecting from anterior border of abdomen (Figures 11, 21). Lateral flaps with electric blue circular 'eye' patch anteriorly near edge of flap; 'eye' patch almost entirely encircled with red-orange anteriorly (stripe B), remainder of flaps rose-gold and bright blue (Figures 12, 13, 21). Long black or dark brown hairs bordering anterior edge of flaps, long creamy hairs laterally (Figures 12, 13).

Legs I, II and IV: proximal half of femora cream dorso-anteriorly and rest dark grey with dark grey patches ventro-posteriorly; tibiae orange and patellae and metatarsi yellow with grey bands at joints; tarsi cream, covered with dense short white hairs interspersed with black bristles. Leg III: proximal quarter of dorsal femur cream, rest dark grey dorsally and ventrally, patella, orange; tibia dark brown; metatarsus orange, tarsus cream. Patella III with thick black brush ventrally, tibia and metatarsus III with thick black brush hairs dorso-ventrally (Figures 14, 20); tarsus III with thick short white hairs on all surfaces and longer white hairs at tip, covering claws (Figure 14).

Pedipalp creamy yellow with scattered greyish patches distally. Tibial apophysis narrow, straight (Figure 17). Cymbium, dorsal tibia and dorsal patella densely covered with long white hairs, a single very long black hair on dorsal pedipalpal patella, tibia and cymbium with a few long creamy and brown hairs on ventral side just under tegulum. Embolus with conductor closely aligned into tight coil, tucked under tip of cymbium; tegulum with two bulges adjacent to embolus (Figure 16).

Female (paratype, WAM T133827)

Ocular region black, densely covered with short black and creamy hairs, rest of cephalothorax with light grey patches grading to greyish-yellow laterally, a broad grey strip extends from posterior of fovea to posterior edge, lightening under a central patch of white hairs (Figure 15). Ocular area with dense cover of short cream and light brown hairs which become longer and more



FIGURES 21–22 *Maratus hortorum* sp. nov., males from Talbot Road Regional Reserve, Western Australia: 21, 13 August 2013; 22, 16 August 2012. Note the variation in the colour patter on the anterior abdomen. (Images courtesy F. Hort, J. Hort.)

dispersed laterally and posteriorly. Clypeus cream; chelicerae yellow with light grey patches, maxillae, labium light yellow with white border. Sternum cream with light grey edging.

Abdomen oval with tan dorsal sigillae and black bristles scattered amongst brown and creamy hairs; most of dorsum covered in dark grey to black patch on light cream background; patch extends to spinnerets (Figure 15), edges of dorsum light cream with scattered dark grey to black patches. Venter of abdomen light cream, with larger dark grey stripes at edges. Dorsal spinnerets dark grey to black, ventral pair pale yellow.

Femora light cream with light grey patches distally, more-so for legs III and IV; patellae of legs creamy, no markings; tibiae, metatarsi and tarsi yellowy, tibiae III and IV with grey bands at joints, rest of leg segments without banding.

Proximal receivers of epigyne short, not meeting across median guide. Intermediate canals shortened, meeting across median guide, angled towards centre of anterior of spermathecae. Insemination ducts opening laterally over spermathecae (Figures 18, 19).

Dimensions (mm)

Holotype (paratype , WAM T133827): total length excluding chelicerae 4.50 (5.45). Carapace length 2.17 (2.18). Abdomen length 2.24 (2.89). Leg I: femur 0.84 (0.83), patella 0.60 (0.57), tibia 0.69 (0.61), metatarsus 0.49 (0.43), tarsus 0.42 (0.43). Leg II: femur 0.84 (0.99), patella 0.42 (0.69), tibia 0.52 (0.47), metatarsus 0.32 (0.34), tarsus 0.28 (0.42). Leg III: femur 1.84 (1.62), patella 0.57 (0.75), tibia 1.10 (0.91), metatarsus 0.98 (0.54), tarsus 0.52 (0.47). Leg IV: femur 1.27 (1.23), patella 0.41 (0.67), tibia 0.60 (0.70), metatarsus 0.93 (0.83), tarsus 0.53 (0.50). Legs, relative lengths: III: IV: II: I (III: IV: II: I).

VARIATION

The colour pattern of males of *M. hortorum* is variable with two broad forms that co-occur: a form with two large red-orange patches on the abdominal dorsum between stripes A and B, either side of the central black patch (see holotype description and Figures 11, 21); and a second form with posteriorly-directed branches extending diagonally from stripe A on either side of the central black patch (Figure 22).

DISTRIBUTION

Maratus hortorum has only been recorded from Talbot Road Regional Reserve in the northern metropolitan region of Perth, at the base of the Darling Range.

REMARKS

Adults of *Maratus hortorum* have been recorded as being active earlier than *M. mungaich*, the latter of which occurs in nearby forests on the Darling Range. Jean and Fred Hort have observed *M. hortorum* as early as June, with pitfall trapped specimens overlapping with *M. mungaich* in mid-winter, June to July.

ETYMOLOGY

The specific epithet is in honour of Jean and Fred Hort, tireless photographic recorders of the natural history at their doorstep.

ACKNOWLEDGEMENTS

I would like to acknowledge the generosity of Madeline Girard for inviting me to accompany her with Prof. Damian Elias on her collecting expedition to south-western Australia as part of her graduate project on the evolution of elaborate male displays and female preference in the peacock spider (*Maratus volans*) at The University of California, Berkley, U.S.A. and The University of New South Wales, Sydney, Australia. Many thanks to Drs Mark Harvey and Michael Rix for their comments on an earlier draft of this paper.

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SHORT COMMUNICATION

Two new records of octocorals (Anthozoa, Octocorallia) from north-west Australia

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KEYWORDS: Stolonifera, Indian Ocean, new locality records, Western Australia; Ashmore Reef, Hibernia Reef, Coelogorgiidae, *Coelogorgia palmosa*, Ifalukellidae, *Plumigorgia hydroides*

INTRODUCTION

In 2012 and 2013 the Western Australian Museum (WAM) undertook a comprehensive biodiversity survey in the Sahul Shelf Bioregion, which encompassed the intertidal and shallow subtidal reef communities of the outer shelf atolls of Ashmore and Hibernia Reefs, and several submerged midshelf shoals. While the outer shelf has seen some octocoral sampling effort in the past, there was no information from the midshelf region (Marsh 1986, 1993; Griffith 1997; Kospartov et al. 2006, Fabricius 2008; Bryce and Sampey 2014).

The eastern section of the Sahul Shelf Bioregion between longitudes 123°20' and 130°46'E is characterised by three platform coral reefs and a series of submerged shoals (Wilson 2013). These structures are true bioherms, built by the accumulation of marine biogenic carbonate during periods of submergence in the Pliocene. While the Kimberley coast is mainly characterised by a low energy wave regime, turbid coastal water conditions, and local tidal currents, the Oceanic Shoal Bioregion has a high wave regime, clear oceanic water conditions and is influenced by the Indonesian Throughflow and Holloway Currents (Wilson 2013).

Examination of octocoral species from these recent surveys, paired with unidentified historic material from the WAM collection has revealed the occurrence of *Plumigorgia hydroides* Nutting, 1910 and *Coelogorgia palmosa* Milne-Edwards & Haime, 1857 in Australian waters. Our intention here is to report on the distribution of these octocorals in Australia and support our findings with molecular analyses for DNA barcoding.

MATERIALS AND METHODS

Material was collected by SCUBA (Figure 1). Specimens were photographed in situ and on deck and preserved in both 70% ethanol for taxonomic investigation and in 100% ethanol for genetic investigation. DNA extraction of preserved tissue was done using a Phenol/Chloroform method. Amplification of the octocoral-specific gene *mtMutS* was performed following standard PCR protocols using primers ND42599F (France and Hoover, 2002) and Mut3458R (Sánchez et al., 2003). The *mtMutS* sequences obtained were initially compared against sequences for congeneric species and afterwards aligned with other octocoral sequences available in GenBank. Maximum likelihood and Bayesian methods were considered for phylogenetic analysis.

Biodiversity surveys were conducted on 30 reef sites over a strip typically 200 to 300 m long and 2 m wide within a 45 minute timed swim. Relative abundances were visually estimated on a rating scale of 0–5: 0 = absent; 1 = one or few colonies; 2 = uncommon; 3 = common; 4 = abundant; and 5 = dominant (Table 1) (Fabricius and De'ath 2001). Historical material from the WAM collection was also examined. All specimens have been registered and deposited in the WAM, Perth.

Site Description: Ashmore Reef (12°17'S, 123°0.2'E) is the largest and most mature platform reef on the north-western side of the Sahul Shelf, 350 km off the Kimberley coast (Wilson 2013). Approximately 26 km long and 14 km wide (150 sq km), it has three low vegetated supratidal cays, a large lagoon and an extensive shoal area less than 50 m deep. The southern and windward reef edge has an unbroken margin. It is backed by extensive sand flats and an outer reef slope characterised by strong surge channels which

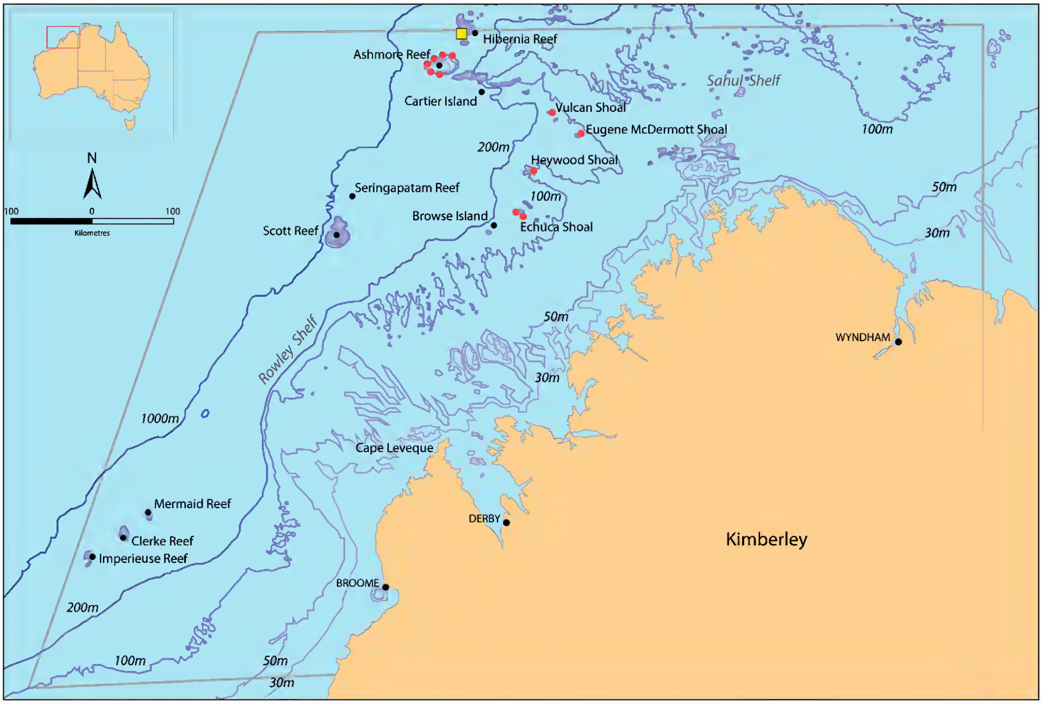

FIGURE 1 Locations of the new octocoral records. The area of study in the Kimberley is bounded by a grey line. Locations of *Coelogorgia palmosa* are marked as red circles and *Plumigorgia hydroides* as a yellow square.

develop into spur and groove formations (Wilson 2013). The leeward northern margins are broken by several passages leading into two extensive shallow lagoons and the outer reef slope is very steep. To the north-east of Ashmore reef is an extensive and complex system of submerged reefs, with only Hibernia Reef being emergent. Hibernia Reef is a coral rich, intertidal platform with a shallow lagoon. To the south-east lie the submerged shoals (Vulcan, Eugene McDermott, Heywood and Echuca Shoals) with hard rock foundation and low coral cover. Locations of the octocoral records are provided in Figure 1.

SYSTEMATIC RESULTS

Family Coelogorgiiidae Bourne, 1900

Monogeneric

Genus *Coelogorgia* Milne-Edwards & Haime, 1857

Monotypic

TYPE SPECIES

Coelogorgia palmosa Milne-Edwards & Haime, 1857 (by monotypy).

DIAGNOSIS

Colonies are aborescent and have a bushy growth form. Axial polyps are very long; lateral polyps are numerous and short. Axial region of colonies is hollow. Primary polyp wall thickened and penetrated by numerous solenia. Sclerites are tuberculated spindles. Stolon reduced to a spreading holdfast. (Williams 1992).

Coelogorgia palmosa Milne-Edwards & Haime, 1857

(Figures 2, 3, 7; Table 1)

Coelogorgia palmosa Milne-Edwards & Haime, 1857: 191; Wright & Studer, 1889: 266–269, pl. 43 figs 1–8; Thomson & Henderson 1906: 435–436; Thomson & Dean, 1931: 215–216; Tixier-Durivault, 1966: 24–25, figs. 7–9; Verseveldt, 1971: 4–5; Williams, 1992: 266.

MATERIAL EXAMINED

WAM Z66904, three whole specimens, Station 122/K13, Ashmore Reef, NW Australia, 12.23065°S, 122.99998°E, SCUBA, depth 12 m, collected M. Bryce, 25 September 2013; WAM Z67016, four whole specimens, Station 132/K13, Ashmore Reef, NW Australia, 12.17297°S, 123.06116°E, SCUBA, depth 14 m,

TABLE 1 Habitat description from stations were *Plumigorgia hydroides** and *Coelogorgia palmosa* were reported. Stations in Marsh (1993) correspond to stations in this report in parenthesis. Relative abundances of octocoral genera: 1 = one or few colonies; 2 = uncommon; 3 = common; 4 = abundant.

Station	Location	Depth (m)	Abundance	Habitat
107 108	Echuca Shoal	22 19	1 1	Wave and current swept isolated shoal – mostly bare rock, coarse coralline sand and rubble with small to medium rocky outcrops. Undercut sections of the outcrops supported a rich variety of benthic invertebrate life.
109 148	Heywood Shoal	23 23	1 1	Wave and current swept isolated shoal – mostly bare rock, coral boulders, tunable rocks, and rocky outcrops. Shallow surge channels with coarse coralline sand. Low profile ledges provide a concentration point for marine invertebrate life
122	Ashmore Reef	12	3	Lagoon – back reef at edge of channel dotted with large flat topped coral outcrops and ridges, fine sediment and coral rubble. Outcrops festooned with soft corals, sponges and some isolated hard corals.
132 (13)	Ashmore Reef	14 (12)	3	Outer reef slope – steep cemented reef slope with coral rubble and *Halimeda distorta*. Soft coral and hard coral communities were diverse, but scattered as individual colonies.
133	Ashmore Reef	13	4	Outer reef slope – high energy fore-reef front consisting of pavement with many small to medium outcrops, with soft corals, sponges and hard corals, including branching and plate *Acropora*.
135 (4)	Ashmore Reef	13 (15)	3	Outer reef slope – high energy fore reef station swept by wave action and strong currents. Reef pavement with shallow surge grooves were dominated by *Sinularia* and *Lobophytum*, and *Halimeda*.
136	Ashmore Reef	6	1	Lagoon – sand, rubble, and rhodolith field with isolated coral outcrops with encrusting corals, plate *Acropora*, soft corals and hydroids.
139 (19)	Ashmore Reef	13 (20)	1	Lagoon – large outcrop with sloping (45°) sides supporting a high diversity of corals and two species of giant clam. Whole site was dusted with fine coralline silt.
142*	Hibernia	20	1	Outer reef slope – sloping reef front dropping to 30+ m to a sand and rubble bottom with a diverse coverage of soft and hard corals with the occasional larger outcrop rising above the slope.
146	Vulcan Shoal	20	1	Wave and current swept isolated shoal – mostly bare rock, coarse coralline sand and rubble with small to medium rocky outcrops, and some large monolithic hard coral colonies. Rocky outcrops with abundant soft corals, and branching and plate *Acropora*.
147	Eugene McDermott Shoal	20	1	Wave and current swept isolated shoal – mostly bare rock covered with algal turf, coarse coralline sand and wide, but shallow, surge grooves filled with rubble and small to medium sized rocky outcrops.

collected M. Bryce, 29 September 2013; WAM Z67023, five whole specimens, Station 133/K13, Ashmore Reef, NW Australia, 12.27478°S, 122.98128°E, SCUBA, depth 13 m, collected M. Bryce, 30 September 2013; WAM Z67064, three whole specimens, Station 139/K13, Ashmore Reef, NW Australia, 12.24147°S, 122.99586°E, SCUBA, depth 13 m, collected M. Bryce, 2 October 2013; WAM Z67124, four whole specimens, Station 146/K13, Vulcan Shoals, NW Australia, 12.79930°S, 124.26672°E, SCUBA, depth 20 m, collected M. Bryce, 6 October 2013; WAM Z67138, one whole specimen, Station 147/K13, Eugene McDermott Shoals, NW Australia, 13.07686°S, 124.58352°E, SCUBA, depth 20 m, collected M. Bryce, 6 October 2013; WAM Z67184, one whole specimen, Station N55, Pilbara, NW Australia, 20.33722°S, 115.56782°E, SLED, depth 45 m, collected D. Thomson, 2013; WAM Z66635, one whole specimen, Station 107/K12, Echuca Shoals, NW Australia, 13.89635°S, 123.89476°E, SCUBA, depth 22 m, collected M. Bryce, 18 October 2012; WAM Z66642, one whole specimen, Station 109/K12, Heywood Shoals, NW Australia, 13.43058°S, 124.01858°E, SCUBA, depth 23 m, collected M. Bryce, 19 October 2012; WAM Z66643, one whole specimen, Station 109/K12, Heywood Shoals, NW Australia, 13.43058°S, 124.01858°E, SCUBA, depth 23 m, collected M. Bryce, 19 October 2012; WAM Z67192, one whole specimen, Station 4, Ashmore Reef, NW Australia, 12.24369°S, 122.24369°E, SCUBA, depth 15 m, collected L.M. Marsh, 12 September 1986; WAM Z67193, five whole specimens, Station 13, Ashmore Reef, NW Australia, 12.17297°S, 123.06116°E, SCUBA, depth 12 m, collected L.M. Marsh, 16 September 1986; WAM Z67194, one whole specimen, Station 19, Ashmore Reef, NW Australia, 12.24147°S, 122.99586°E, SCUBA, depth 20 m, collected L.M. Marsh, 19 September 1986; WAM Z67184, one whole specimen, Station 56551, Pilbara, NW Australia, 20.33722°S, 115.56782°E, sled, depth 45 m, collected D. Thomson, 2013. Additional material was reported and examined in situ by M. Bryce from the following stations, but not collected: Station 108/K12, Echuca Shoals, NW Australia, 13.90069°S,

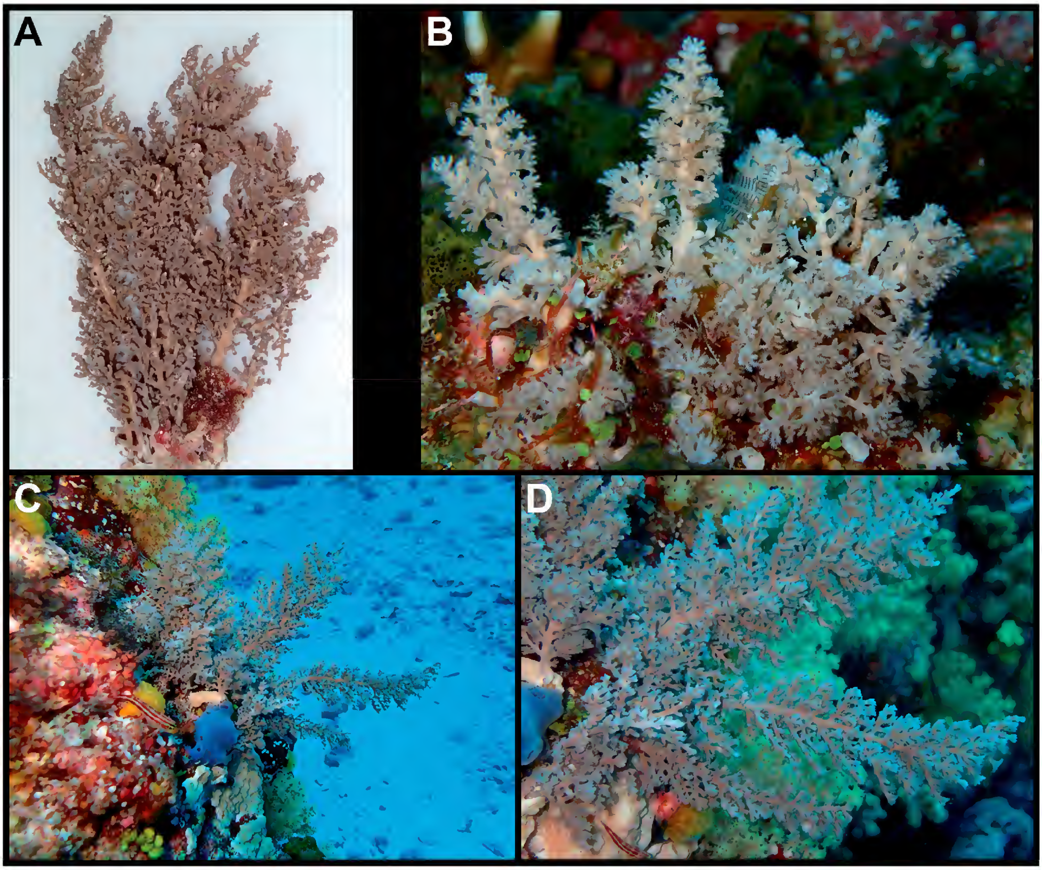

FIGURE 2 *Coelogorgia palmosa* WAM Z66642 (A, B) and WAM Z66643 (C, D) A. On deck; B–D. in situ.

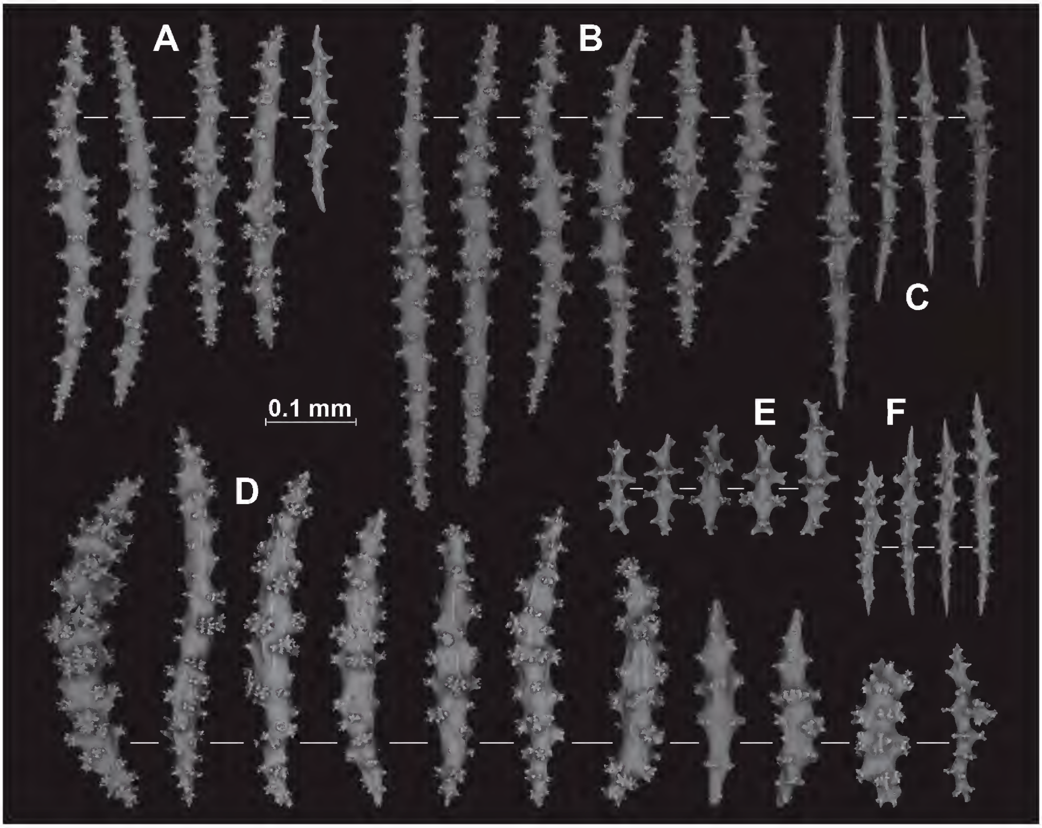

FIGURE 3 *Coelogorgia palmosa* WAM Z67064 sclerites. A. Surface of the branches; B. Interior of the branches; C. Surface of the stem; D. Interior of the stem; E. Polyp body; F. Tentacles.

123.89345°E, SCUBA, depth 19m, 18 October 2012; Station 135/K13, Ashmore Reef, NW Australia, 12.24369°S, 122.24369°E, SCUBA, depth 13m, 1 October 2013; Station 136/K13, Ashmore Reef, NW Australia, 12.19448°S, 123.05015°E, SCUBA, depth 6m, 1 October 2013; Station 148/K13, Heywood Shoals, NW Australia, 12.44741°S, 124.03244°E, SCUBA, depth 23m, 7 October 2013.

DESCRIPTION

The colonies are bushy and aborescent (Figure 2A–D). They vary in size, but in general, are very similar in shape, colour, arrangement of polyps and sclerite composition. The colonies consist of a stem and branches which are arranged in alternate succession and branch off the main stem at steep angles. The branches may bear twigs. The colonies are between 36–360 mm tall and 11–126 mm wide, with the side branches being between 10–66 mm long and mainly between 4–9 mm wide. The thickness of the stem above the base varies between 2–7 mm. All colonies are 'rigid and brittle, with only the twigs having a slight elasticity' as described by Wright and Studer 1889. The polyps are not retractile. The axial polyps are very long, the lateral polyps are short and numerous. The spicules are distributed through the entire colony, including the tentacles, and consist of straight and curved spindles with spinose warts. On the surface and in the interior of the branches the sclerites are mainly between 0.20–0.45 mm long (Figure 3A, B). On the surface of the stem the sclerites are between 0.15–0.30 mm long and in the interior coenenchyme of the stalk between 0.30–0.40 mm long (Figure 3C, D). Sclerites in the polyp body measure between 0.25–0.40 mm in length and tentacle sclerites are between 0.20–0.26 mm in length (Figure 3E, F).

Colour: In situ the colonies were uniformly cream to light brown and slightly darker on deck (Figure 2). In alcohol specimens are cream to light brown. Sclerites are colourless.

Habitat: Outer and fore reef slopes, lagoons, and submerged shoals (Table 1).

Remarks: Our material fully agrees with the detailed description of *C. palmosa* by Wright & Studer 1889 in growth form and all other morphological features.

Family Ifalukellidae Bayer, 1955

Genus *Plumigorgia* Nutting, 1910

Plumigorgia Nutting, 1910: 32; Alderslade 1986 3(1): 117.

TYPE SPECIES

Plumigorgia hydroides Nutting, 1910 (by monotypy).

DIAGNOSIS

Colonies pinnately branched, planar to compressed or bushy with small calcified holdfasts. Axis calcified, but flexible. Polyps monomorphic, small, forming low mounds or completely retractile within the general coenenchyme and may have sclerites. Coenenchyme may be very thin or very thick. Sclerites absent to abundant, small, occurring in the shape of ovals, sub-spheroids, peanuts, crosses, multiradiate stars, and irregular shapes. Sclerites colourless. (Alderslade 1986, Fabricius & Alderslade 2001).

Plumigorgia hydroides Nutting, 1910

(Figures 4–6, 7; Table 1)

Plumigorgia Nutting, 1910: 32–33, Plate IX, Figs. 3, 3a; Plate XI, Fig. 4; Alderslade 1986 3(1): 115, 117, Fig. 20.

MATERIAL EXAMINED

WAM Z67094, one whole specimen, Station 142/K13, Hibernia Reef, NW Australia, 11.98815°S, 123.33585°E, SCUBA, depth 20 m, collected M. Bryce, October 2013.

DESCRIPTION

In situ the colony shows a bushy appearance with the branches being arranged in irregular parallel rows, i.e. planar (Figure 4). The preserved specimen is profusely branched in one plane with a main stem of approximately 6 mm in diameter (Figure 5). It is 285 mm in height and 170 mm wide. The calcified axis is round, but most of the branches are slightly laterally flattened due a bilateral thickening of the thin coenenchyme. The colony shows some degree of bushyness with some branches diverging 'out of plane', turning vertically and ramifying more or less parallel to the main plane (Figures 4, 5). The first major branching occurs 33 mm up from the place of attachment, where the main stem divides into two branches. Further branching occurs above this point into numerous smaller branches. The branches are between 35–60 mm long. From the latter terminal twigs arise in an alternating pinnate mode. They are between 6–14 mm long, and slightly expanded at their base of attachment. The fine hair-like nature of the axis of the terminal twigs is quite evident, making the colony resemble a 'plumularian hydroid' as described by Nutting 1910. The polyps are numerous on the terminal twigs with approximately 0.1 mm between centers. They are arranged biserially, often opposite, but also sub–opposite or alternate (Figure 4B). They are totally retractile into the general coenenchyme. The apical end of the twigs is often devoid of polyps. On the branches polyps are also arranged biserially, but are fewer and more irregularly distributed, becoming scarce in older parts of the colony.

The small sclerites are densely aggregated over the whole colony, with the exception of the shiny golden-brown coenenchyme of the stem and main branches. Under the microscope the sclerites of the twigs appear as a densely aggregated white layer. They are derived from basic rod shapes with the majority of sclerites being somewhat rectangular and fewer being circular–oval (Figure 6). Often the oval is constricted in the middle producing a peanut-shape. The majority of sclerites are between 0.03–0.05 mm long and 0.01–0.03 mm wide, with the surface covered by fine granules. There was no distinct difference in sclerite shape or size between the upper or lower terminal twigs in the colony, nor between

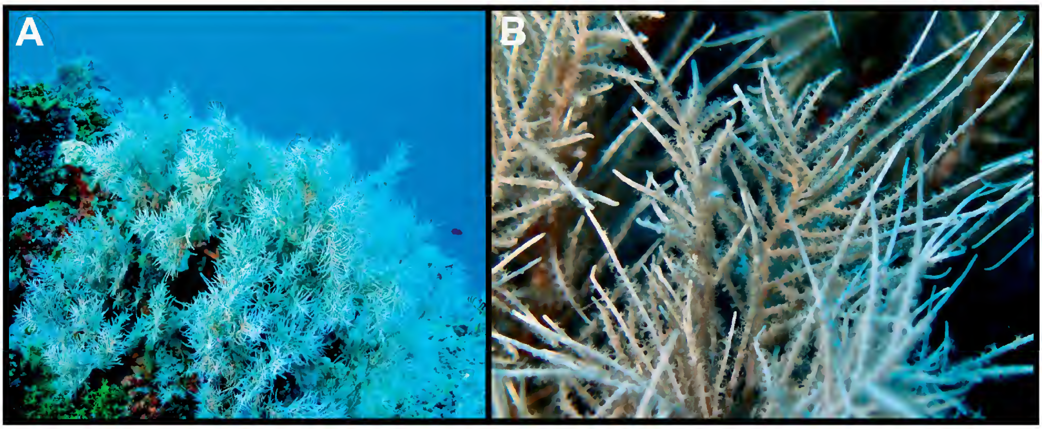

FIGURE 4 A, B. *Plumigorgia hydroides* WAM Z67094 in situ.

the apical ends of the twigs or the parts attached to the stem.

Colour: In situ and on deck the colony was yellowish–white with a golden-brown stem (Figures 4, 5). The preserved specimen has the same colour. Sclerites are colourless.

Habitat: Fore reef slope (Table 1).

Remarks: Our material agrees with the description and detailed analysis of *P. hydroides* by Alderslade (1986). That author also discusses the usage of overall growth form for identification and the possibility of ecotypic variations in colony shape. It is possible that for many species planar and non-planar forms exist. Unfortunately descriptions are often based on preserved colony fragments with little documentation of how the colonies grow in situ. Also, specimen shape and appearance can change during storage and handling causing degradation of the sample.

MOLECULAR ANALYSES

In octocorals the mitochondrial locus *mtMutS*, has been extensively used for the molecular analysis and provides the most complete taxonomic coverage available for the subclass (e.g. McFadden et al. 2006). However, for this contribution the main goal was not to reconstruct the molecular phylogeny, but rather to corroborate the morphological results. *mtMutS* sequences obtained for *Coelogorgia* (WAM Z67064)

FIGURE 5 *Plumigorgia hydroides* WAM Z67094 photographed on deck.

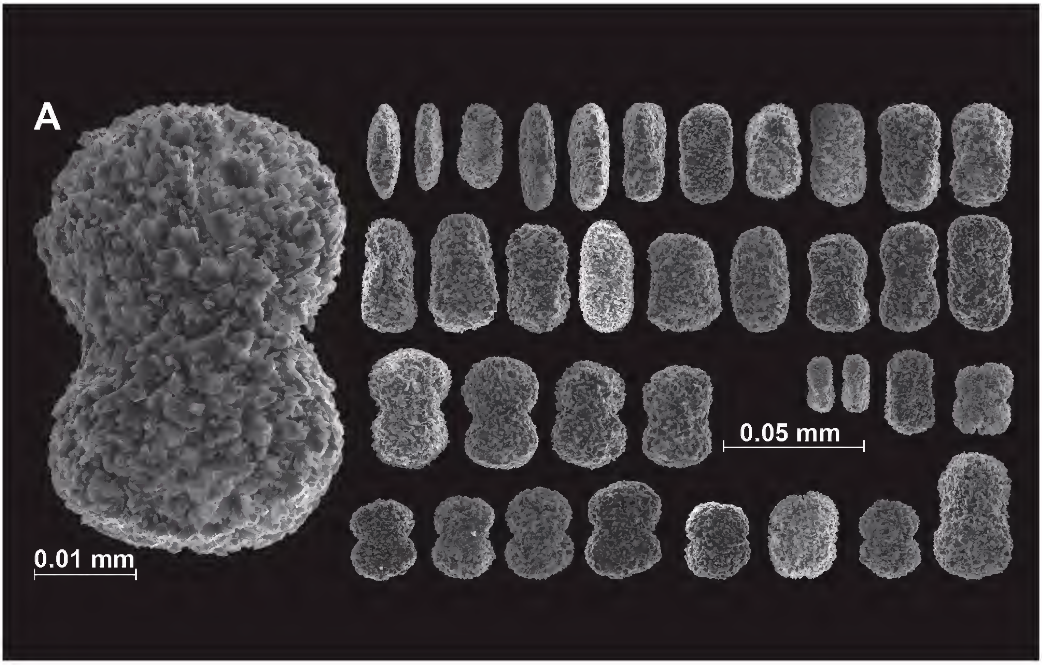

FIGURE 6 *Plumigorgia hydroides* WAM Z67094 sclerites. A. detail of surface; B. range of shapes.

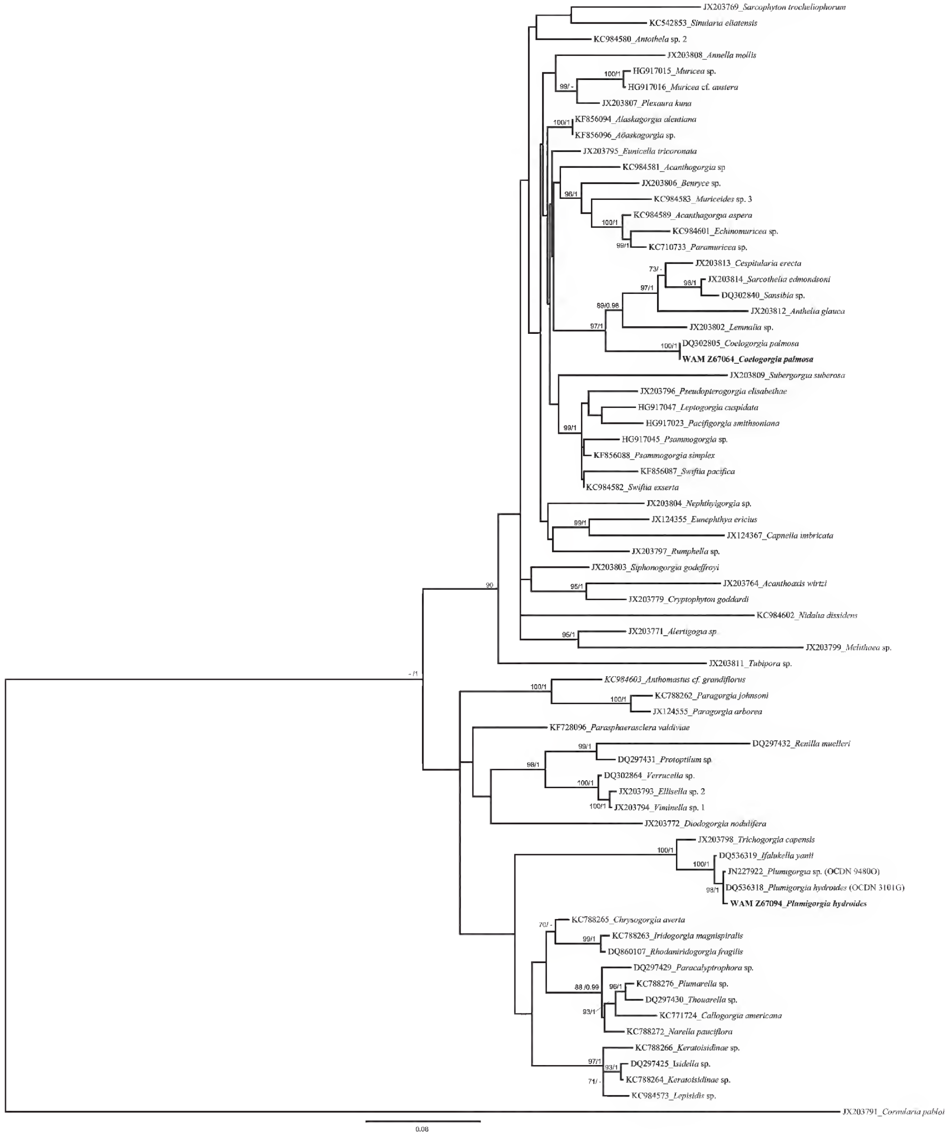

FIGURE 7 Maximum likelihood tree of *mtMutS*. Values at the nodes refer to bootstrap (left) and posterior probability (right). Alphanumeric codes before species name represent GenBank accession numbers, in brackets are museum vouchers. *Cornularia pabloi* was used as the outgroup.

and *Plumigorgia* (WAM Z67094) match respectively 100% with the *Coelogorgia palmosa* (DQ302805) and 99% with the two *Plumigorgia* (*P. hydroides* and *P.* sp.) (DQ536318, JN227922) sequences downloaded from GenBank. The two phylogenetic methods supported the same tree topology (Figure 7). Specimens belonging to *Plumigorgia* grouped together with two Ifalukellidae species (*Ifalukella yanii* and *Trichogorgia capensis*), well supported by both bootstrap and posterior probability values. The Stolonifera group is considered to be polyphyletic (McFadden and Ofwegen 2012).

SUMMARY

Here we report on two new Australian geographical records of the bushy octocorals *Plumigorgia hydroides* and *Coelogorgia palmosa* from outer reefs and mid shelf shoals off the Kimberley coast, Western Australia. Biological surveys were undertaken at 24 Ashmore and Hibernia Reef stations, and at six stations at isolated submerged shoals in the mid shelf region.

The genus *Plumigorgia* has been reported from the Great Barrier Reef, the Chesterfield and Marshall Islands and Micronesia in the Pacific, from Indonesia in the Indian Ocean, and also from the China Sea (Alderslade 1986, Fabricius & Alderslade 2001, Grasshoff & Bargibant 2001). This is the first record for this genus in Western Australia. From five species described within this genus three are described from Australian waters, *P. astroplethes* Alderslade, 1986, *P. schuboti* Alderslade, 1986, and *P. terminosclera* Alderslade, 1986, but were only recorded from the Great Barrier Reef off the east coast of the continent. The other two described species are *P. wellis* Bayer, 1955, collected from the central West Pacific, and *P. hydroides* Nutting, 1910 formerly only collected from central Indonesia. This is the first time *P. hydroides* has been collected in Australia. Occurrence was extremely low with the species found only at one site at Hibernia Reef occupying about 1 m^2 in area.

In contrast, the second new Australian record, the monotypic *Coelogorgia palmosa,* had a surprisingly wide distribution and high abundance at some stations (Table 1). It has been formerly reported from the West Indian Ocean from South Africa (Williams 1992), Mozambique (Wright & Studer 1899, Tixier-Durivault 1966, 1972), the islands of Zanzibar, Madagascar (Tixier-Durivault 1966, 1972, Verseveldt 1971) and the Seychelles (Milne-Edwards & Haime 1857). In the Pacific Ocean it has been collected from Indonesia (Thomson & Dean 1931) and Palau (McFadden et al. 2006).

In Australia, *Coelogorgia* sp. was mentioned for the first time by Marsh (1993) from Ashmore Reef. The specimens were collected in 1986 at three sites and stored at WAM. The significance of this discovery had been overlooked and the specimens are now identified in this work as *C. palmosa*. Department of Environment and Heritage (Kospartov et al. 2006) reported *C.* sp. from a single station at Ashmore Reef, but no specimens were collected. During the WAM survey, *C. palmosa* was collected from six Ashmore Reef sites and four mid shelf shoal sites, while it was absent from the other 18 Ashmore and Hibernia Reef stations. While the abundance at some Ashmore Reef stations was remarkably high, with up to 100 colonies counted per dive, abundance at sampled mid shelf shoals was low (Table 1).

This survey was part of a WAM led project funded by Woodside Energy, and since 2009 148 stations have been completed from inshore to outer shelf sites. Additional data from various Australian museum historical collections and both published and unpublished survey datasets were also considered. These included datasets from Western Australian locations at Ningaloo Reef, the Pilbara coastal regions and the Rowley Shoals, and from Great Barrier Reef sites along Australia's east coast. (Marsh 1986, Griffith 1997, Fabricius 2008, Keesing et al. 2011, ABRS 2011, Bryce unpublished – Pilbara and King George surveys 2013 and 2014). Searching this data revealed no occurrence of *P. hydroides* or *C. palmosa* from the Great Barrier Reef, which was further confirmed by other researchers who had undertaken octocoral surveys from the region (Katharina Fabricius, unpublished; Phil Alderslade, unpublished). However, in 2013 one new specimen of *C. palmosa* was dredged from 45 m near the Montebello Islands off Western Australia's Pilbara coast by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), suggesting a wider distribution for this species along this coast, mostly unsurveyed for octocorals.

This highlights the importance of comprehensive surveys in remote areas in providing a clearer understanding of octocoral taxonomy, systematics and distribution patterns in tropical marine environments. Growing Octocorallia collections will reveal essential biogeographic data from this poorly studied area of the Western Indian Ocean (Bayer 1981), with implications for marine area protection (Fabricius 2008, Keesing et al. 2011, Richards et al. 2013).

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